

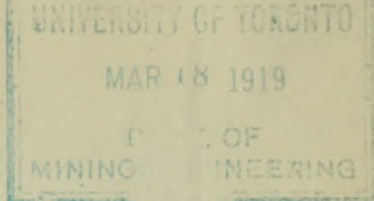
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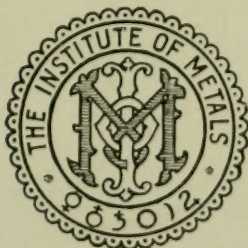
VOLUME XVI

EDITED BY

G. SHAW SCOTT, M.Sc.

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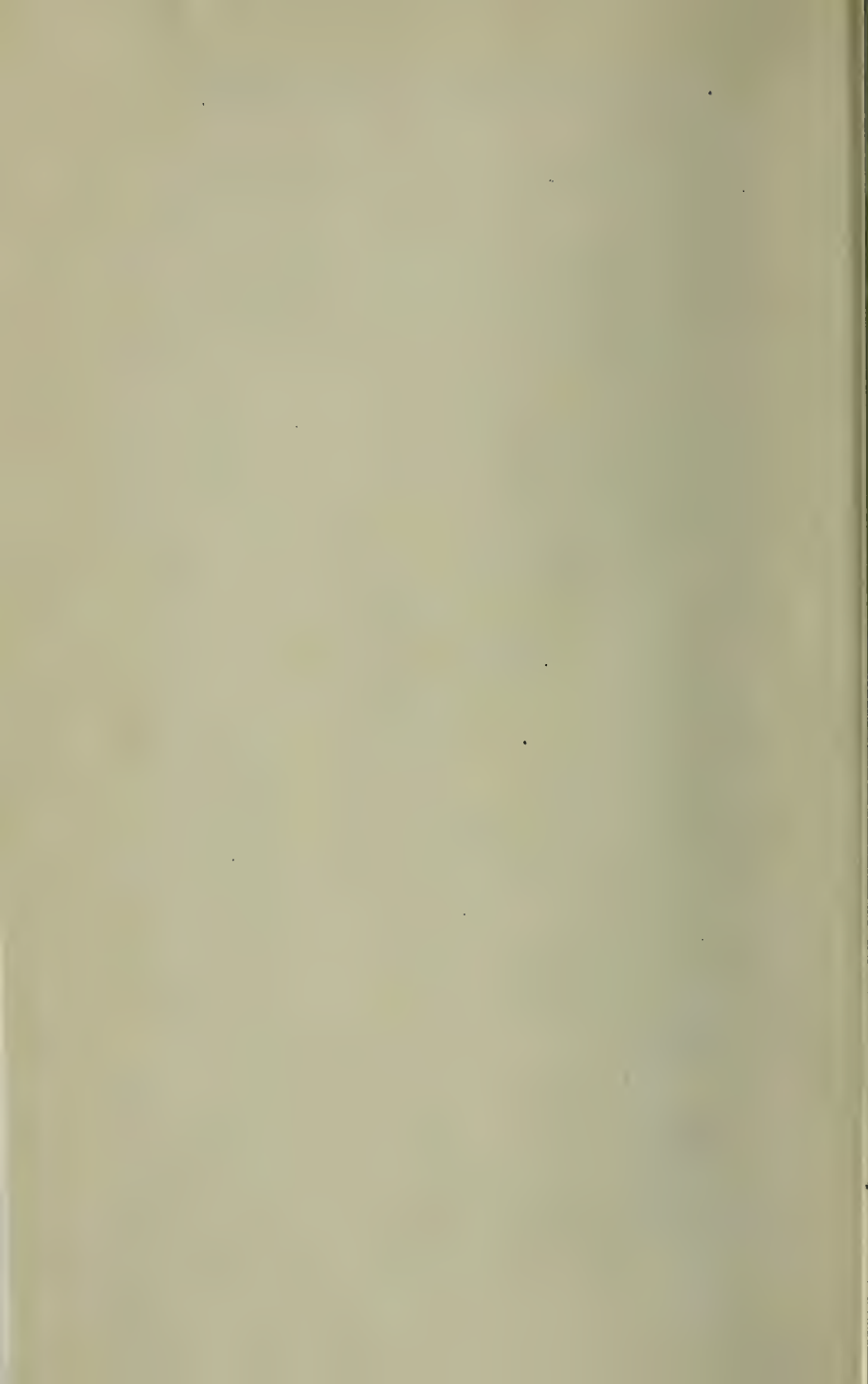
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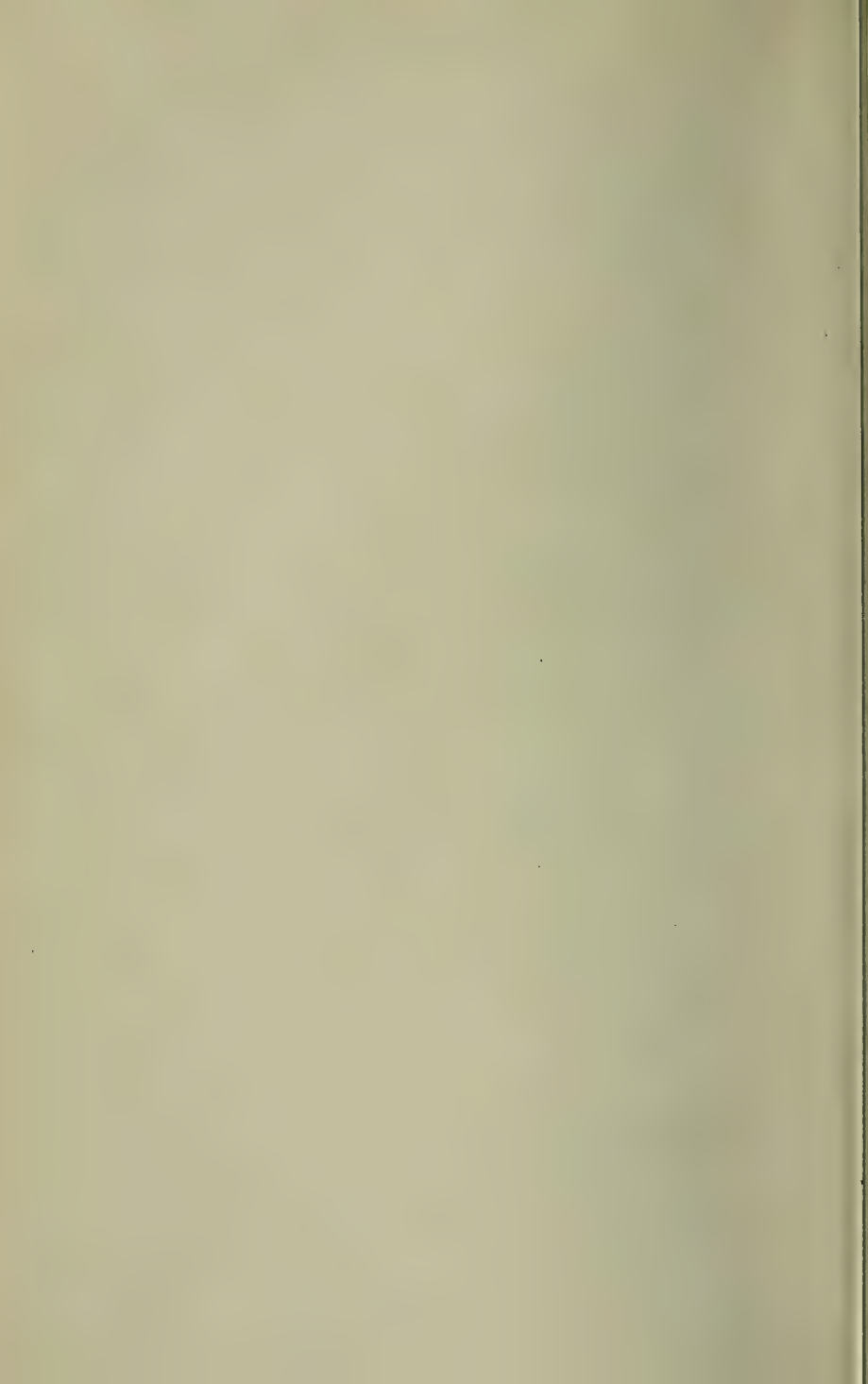
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THE INSTITUTE OF METALS

SECTION I.

MINUTES OF PROCEEDINGS.

MAY LECTURE.

At a GENERAL MEETING of the Institute, held at the Institution of Electrical Engineers, Victoria Embankment, W.C., in the evening of Thursday, May 4, 1916, Professor H. C. H. Carpenter, M.A., Ph.D., Vice-President, in the Chair, Professor W. H. Bragg, D.Sc., F.R.S., delivered the sixth May Lecture.

The Minutes of the Annual General Meeting, held in London on March 29, 1916, were taken as read, and were signed by the Chairman.

Professor W. H. BRAGG then delivered his lecture on the subject of "X-Rays and Crystal Structure, with special reference to certain Metals," a full report of which will be found on pp. 2-13.

VOTE OF THANKS TO PROFESSOR W. H. BRAGG.

Professor CARPENTER proposed, and Dr. W. ROSENTHAL, F.R.S., seconded, and there was carried unanimously, a hearty vote of thanks to Professor W. H. Bragg for his lecture.

The proceedings terminated at 10 o'clock p.m. with a vote of thanks to the Institution of Electrical Engineers for the use of rooms for that meeting.

1916 MAY LECTURE.*

X-RAYS AND CRYSTAL STRUCTURE, WITH SPECIAL REFERENCE TO CERTAIN METALS.

BY W. H. BRAGG, D.Sc., F.R.S.

(QUAIN PROFESSOR OF PHYSICS IN THE UNIVERSITY OF LONDON).

IT will be my endeavour this evening to describe to you the new method of analyzing the structure of materials which are crystalline. It depends upon the use of X-rays, and I must therefore tell you something of those properties of the X-rays which are concerned, and afterwards give you an account of a few applications of the method and of the results obtained.

When successful, the new method results in the determination of the exact relative position of the atoms of which a crystal is composed. It has not as yet been applied to any but the simpler forms of crystals. It is a new science and must learn to walk before it tries to run. As progress is made more and more complex forms will no doubt be resolved. As experimenters in a new field we require practice, and moreover, we are not yet fully acquainted with the proper interpretation of many of the new facts which we observe. As time goes on, experience both in experiments and in interpretation will give us ever greater and greater command of the methods of the new research.

Let us begin then by a description of some of the more pertinent properties of X-rays.

They constitute, as we are aware, a form of radiation in which energy travels through space in straight lines. The rays are detected either by their action on a photographic plate or by the phosphorescence which they can produce on suitable screens, or by a certain curious effect upon a gas through which they pass. They are able, as we say, to ionize that gas; this means that some

* Delivered May 4, 1916, in the Hall of the Institution of Electrical Engineers, London.

of the atoms or molecules of the gas are affected by X-rays, the result being that each atom affected loses an electron which, in general, attaches itself to some other neighbouring atom. This has an electric consequence—the atom which has lost the electron is positively charged, that which has gained it is negatively charged. When electric force is applied the positive may be driven one way, the negative the other, and either can be swept as a charge into an electroscope or other instrument for measuring electrical quantity.

As a rule we use the last of these three methods in laboratory work with X-rays, and in particular, with the work I am about to describe. We cannot see X-rays, and the apparatus built to detect the ionizing effect constitutes an artificial eye specially designed for X-ray vision.

We have been in the habit of measuring the effects of X-rays by one or other of these means ever since their discovery twenty years ago, but while we have become familiar with the treatment of the rays, we have long been in doubt as to their nature. Many of the properties of the rays seem to indicate that they consist of streams of small energy-carrying centres of some sort. Others again are more in agreement with the hypothesis that they are, like light, a form of wave motion in the ether, and that the study of X-rays is but one chapter of the greater study of light. This is in spite of the fact that X-rays cannot be reflected or refracted as light can.

It is one of the results of the new method that fresh light is thrown upon the nature of X-rays. We find that they are as much a wave motion as light is, but there is a difference of degree, because the waves of light are perhaps one fifty-thousandth of an inch long, while the waves of X-radiation are ten thousand times shorter.

My immediate object is, in fact, to show you how certain X-ray effects are exactly analogous to certain effects of light, only that they are worked on a ten thousand times finer scale.

There is one optical effect familiar to all of us which is the basis of all that I have to say: that, when light is reflected from a very thin film, such as the wall of a soap-bubble or the thin sheet of oil that spreads over a pool of water into which tar or oil is dropped, brilliant colours of the spectrum are displayed by

the reflecting beam. Newton investigated this effect long ago.

The explanation of the phenomenon is not at all difficult.* Imagine a train of waves to be incident upon one surface of the soap film. A certain reflection of these waves takes place at the first surface, but some of the light goes on into the film and arrives at the second surface, where it is again divided. Following only that part which is reflected we find another division taking place when it once more meets the upper surface, and finally a certain portion emerges again from the film on the same side as that on which the first ray fell. Thus we have two reflected beams and, indeed, more, because the beam within the film will, so to speak, ricochet from side to side sending out a certain reflected beam into the open every time it strikes the upper surface.

The question is—what do all these reflected beams amount to when they are put together? Now comes a fundamental theoretical point: the reflected ray that emerges after having twice crossed the film has covered a little more ground than the reflected ray which has never entered the film at all. Suppose that it had just got one wave-length behind, such an effect would never be noticed, because the two waves would still run together, crest to crest and hollow to hollow. But if the loss was half a wave-length or a wave-length and a half or two wave-lengths and a half, and so on, the two reflected waves would be absolutely out of step, and, according to the well-known optical effect, they would destroy one another, and there would in fact be no reflection at all.

The lag of one wave behind the other measured in wave-lengths depends upon three things—the length of the wave, the thickness of the film, and the angle of incidence.

When the right relation holds between these quantities the reflected waves all conspire together and the reflection is good; when it does not the reflection is so much the worse. The explanation of the colour of the soap bubble, or any thin film of the kind, is now easy.

When white light, containing all wave-lengths and colours, falls upon the film it will depend upon the thickness of the film and the angle of incidence what wave-lengths will most be

* For a fuller description of this point see *X-Rays and Crystal Structure*, by W. H. Bragg and W. L. Bragg, p. 16. G. Bell & Sons.

reflected ; some colours will be, as it were, selected for reflection and others will not. If the angle is changed or if the film grows thinner the colour alters.

Now let us carry this one stage further. Suppose there are not simply two reflecting surfaces as in the case of the film, but a large number one behind the other. Such cases do occur in nature though with far less frequency, one of the best known instances being that of the crystals of chlorate of potash. When this crystal grows it has a peculiar habit of appearing in two forms, one the twin of the other. The crystals are naturally formed in thin wafers, and these consist of thousands of strata alternately formed of the two kinds. For some unknown reason the strata are very even, and as regards any one crystal are all alike in thickness. When a ray of light enters such a crystal it finds a reflecting surface at every boundary separating the two kinds, and the reflected beam which emerges is made up of the thousands of minor pencils which have come from the multitude of reflected surfaces. If the relation of which we have already spoken is exactly fulfilled, the various reflected pencils will have lost, in respect to the original, one, two, three or more complete wave-lengths. All will naturally join together and the reflection as a whole is good.

But in this case, if the relation is not exactly fulfilled the falling away in the intensity of the reflection is not gradual, as when there were only two surfaces, but is very abrupt and complete.

The crystals of chlorate of potash will pick up from incident white light falling at a certain angle, only an extremely narrow range of wave-length, and it is this that gives the brilliant colour. The colour of opals is due to the same cause.

Lord Rayleigh explained this action at the Royal Institution long ago. It is not nearly so well known as the simpler phenomenon of the single film.

It is to this effect that we find the parallel in the case of X-rays. That there should be such a parallel demands that the spacing of the reflecting planes should bear the same sort of numerical relation to the wave-length of the X-ray that the thickness of these chlorate of potash strata bears to the wave-length of light. The two quantities should, in each case, be of somewhat the same order.

Where are we to find the structure in which there are reflecting layers ten thousand times closer together than the twinning layers of the crystal we have been considering? That these actually exist in nature has been shown to us mainly by two men. The first of these was von Laue, Professor of Zurich, who pointed out that the regular distances between atom and atom in the crystal might be expected to do for X-rays what the same sort of arrangement on a grosser scale does for light; as for example in the colours of mother-of-pearl, or insects' wings, or the regular diffraction grating of the laboratory. The second was my son, who pointed out that the regularity of arrangement of the atoms in a crystal made it possible to think of them as all arranged in layers, that these layers could be looked on as reflecting surfaces, and that the same argument could then be applied as in the already known analogous case of light.

That a layer of atoms can be looked upon as a reflecting surface may seem strange. We are apt to think that reflecting surfaces must be continuous, but it is not so—a row of palings can, for example, reflect sound and give an echo.

We are now brought to the last stage of the explanation of the new method. Let us suppose we have a beam of X-rays of given wave-length, and that we allow this beam to fall upon the natural face of a crystal. The regularity of crystal structure obliges us to suppose that the natural crystal face contains a layer of atoms and that behind these are other parallel and exactly similar layers equally spaced one behind another. All taken together, they form the crystal itself.

Suppose the beam of X-rays is incident upon this set of layers at a certain angle. If the relation between wave-length, spacing, and angle, of which we have already spoken, is satisfied, there will be a reflection; if not there will be none. It is a very precise phenomenon indeed. The angle of incidence must be set to a very few minutes of arc if the reflection is to take place. We may turn the crystal round, gradually letting X-rays play on its face the whole time, and there will be no reflection until we arrive at the exact angle; then it flashes out and we can register its existence by the electrical method I described at the beginning. Suppose that we note down the angle. Now let us take another face of the same crystal and find the angle,—it will not be the

same if the face is not similar from a crystallographer's point of view. We may do this to several faces. We may prepare faces specially if they do not already exist; and it is to be observed that there is no need to polish the face or even to make it quite true, because the reflection is not at the surface but from the volume within, and the crystal will look after its own angles.

Now let us see what use we can make of the information we have got. If we stand in a vineyard we can see avenues running down the vines in all directions. If we were told the widths of these avenues we could make a plan of the vineyard. In exactly the same way, if we are told the spacings of various sets of planes in a crystal parallel to natural faces, or to faces we have prepared ourselves, we can, so to speak, draw a map of the crystal. This is in fact the procedure which is actually adopted.

It is to be observed that this does not tell us everything. To understand how much it does tell and how much it does not it is perhaps best to consider this simple case.

Here, say, is a wall-paper of very simple pattern (Fig. 1). If we take some representative point, say the tip of a certain ribbon, and mark it wherever it occurs on the paper, we have a kind of lattice of points. In the more complicated wall-paper (Fig. 2) exactly the same sort of thing may still be done. No matter how great the complication we arrive in this way at a simple lattice of points. It is in the unit which is repeated to form the crystal that we find greater or less complication.

In the crystal a certain unit must be repeated again and again, having always the same orientation in space, and always the same relation to its neighbours. If we pick out some one centre of an atom as representing each unit and mark it wherever it occurs we shall arrive at a simple space lattice. The unit itself may contain one, or any number of atoms; and may be quite complicated.

The first fruits of our measurements give us these lattice spacings and enable us to draw in space a map of the representative points. This part of the work is comparatively easy. When we take up a new crystal for examination, knowing already its symmetries and its crystallographic features, it does not take us very long to find the form of the lattice on which it is arranged. Knowing this and the specific gravity of the crystal and the weight of the individual atoms, a very short calculation tells us how many

atoms are contained in the unit which is repeated again and

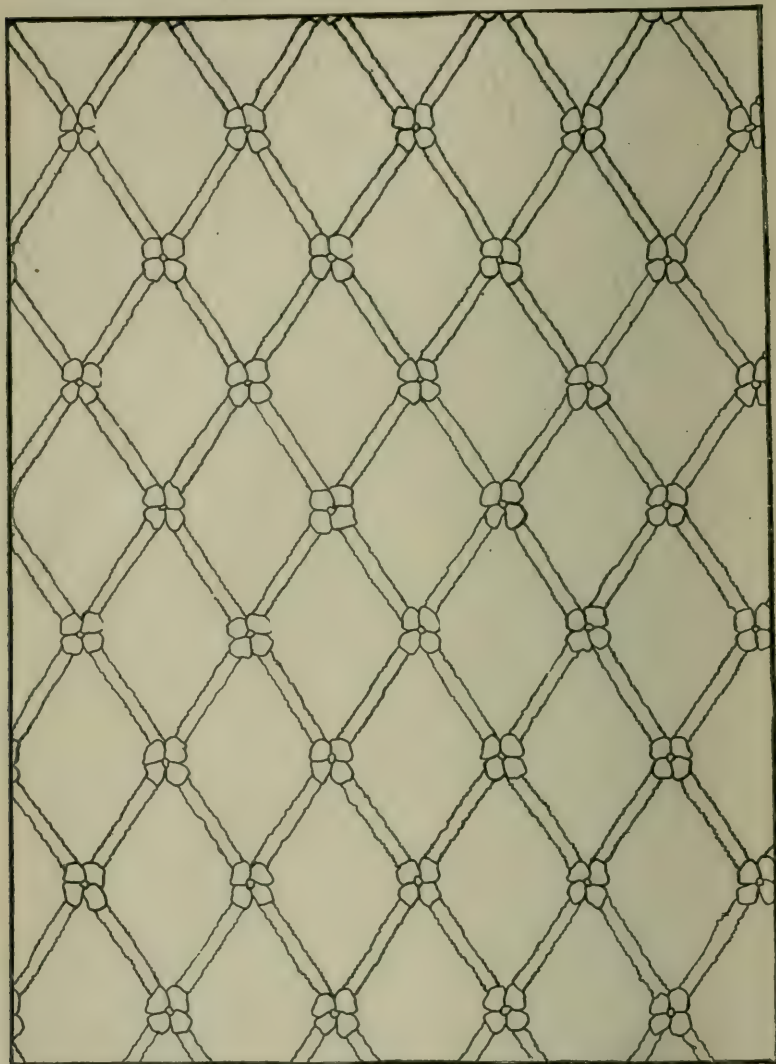


FIG. 1.—A very simple wall-paper pattern. Let the centre of each rosette (or any other representative point) be marked in ink. The ink spots will all lie on a simple lattice.

again through space. For example, in copper there is one atom

to the unit ; in antimony there are two ; in rock salt there is one molecule ; in calcite also one molecule ; in potassium chlorate there appear to be four.

There is a second part of the work which is in general much

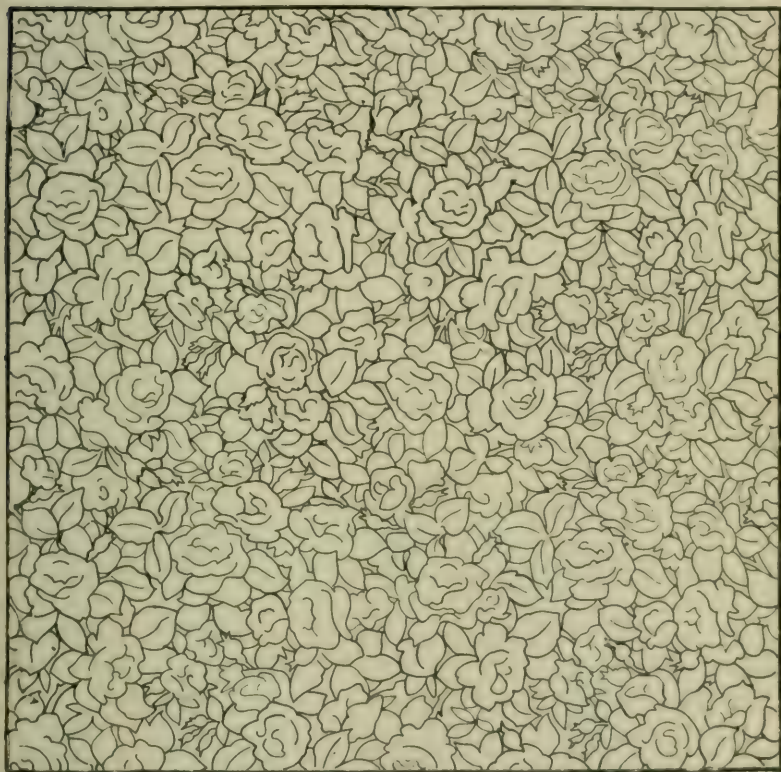


FIG. 2.—Exactly the same can be done in this figure as in the preceding, although it looks so much more complicated. Indeed the lattice is simpler than in Fig 1.

more difficult. It consists in the determination of how the atoms in each unit are arranged about the representative point. Let me try to explain this part of the work also.

It depends upon an entirely different principle, familiar to users of the spectrometer. When a diffraction grating is employed to produce spectra it is well known that the line that comes from the single slit can be resolved into spectra of several orders, and

moreover that these orders are not all equally intense. *The angles at which these spectra are to be found* is a matter of the *spacing of the lines on the grating*, but the *distribution of intensities* among the various spectra is a matter of the *form of the line* on the grating. Two different diamond points used to rule gratings of the same number of lines to the inch would give spectra in absolutely the same places, but there would probably be great differences in the relative intensities of these spectra because the diamonds would not rule grooves of the same form and depth.

Now we pass to the crystal case. Each face of a crystal gives reflections of many orders. Reflection flashes out, not only at one particular angle but one of a series of angles—when in fact the reflections of which we have already spoken lag behind one another by amounts of one wave-length, two, three, and so on. These constitute the different orders and correspond to the different orders of spectra in a diffraction grating.

Now these orders vary also in intensity. The intensities depend on how the atoms are distributed about the representative point of each unit. Our problem is to argue back from the observed effect to the distribution which has caused it. This is a task of much greater difficulty than that of finding the “lattice”; and here lies the explanation of why we have only succeeded as yet with the simpler forms and are obliged to move slowly in our attack on the more difficult.

It would be too great an attempt to go fully in one evening into the details of all the work that is being done,* and I must content myself now with showing you a few simple cases:

Here for example is a model of a crystal of rock salt, where the black balls may be taken as standing for chlorine and the white for sodium, or *vice versa*. You will see the simple cubical arrangement of the whole. Rock salt is well known to possess a cubic form of high symmetry.

Here again is one of fluor spar, also a crystal of very high symmetry and very simple outward form; the red balls here stand for calcium and the white for fluorine.

Here is the diamond, possessing an extraordinarily simple and well-balanced structure. Every atom stands at the centre of a regular tetrahedron formed of its four nearest neighbours. Zinc

* Examples will be found in the book already referred to.

blende has the diamond structure, but alternate layers are formed

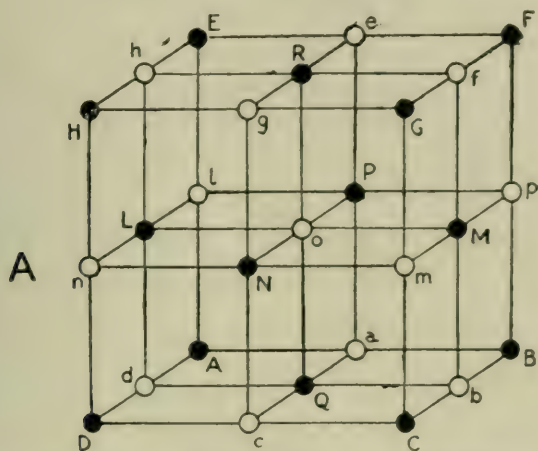


FIG. 3.—Diagram of rock-salt structure. Black dots represent sodium and white chlorine, or vice versa. The representation is as to position only, not to form or size.

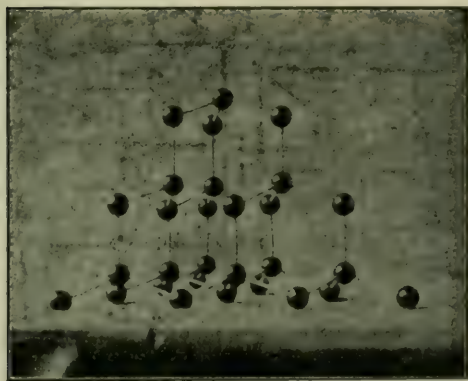


FIG. 4.—Diagram representing diamond structure.

of zinc and sulphur and it gives less symmetry to the outward form, as crystallographers know.

Here again is iron pyrites, showing a greater complexity of structure than in crystals we have had before and explaining the curious symmetry of the crystal.

Here is a very complicated-looking crystal* representing the spinel group, of which magnetite is a member.

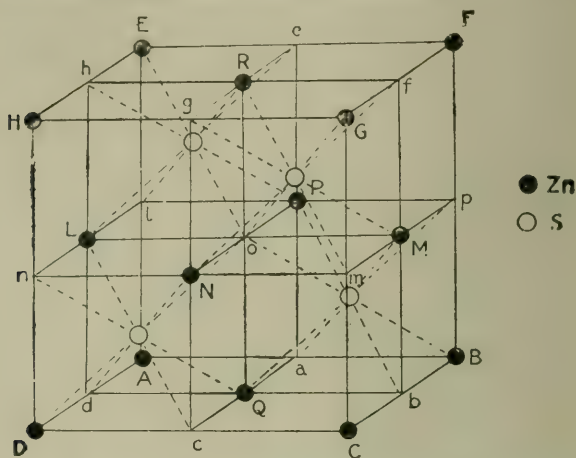


FIG. 5.—Diagram representing the structure of zinc blende.

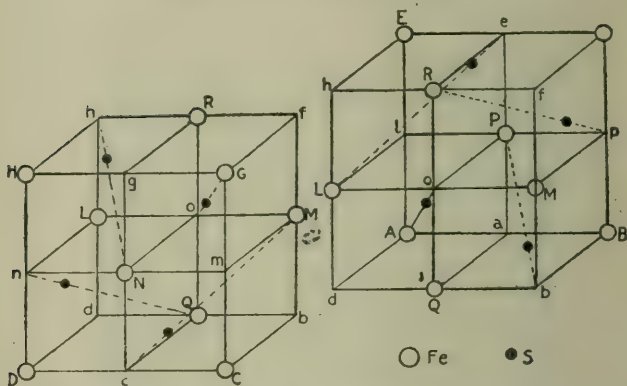


FIG. 6.—Diagram representing the structure of iron pyrites. Being rather complicated the model cube is shown in two halves separated from one another.

Copper possesses a constitution very easily described, for its atoms are arranged exactly like a pile of shot. As crystallographers have shown us, such piling can be of two kinds, one leading to a cubic crystal, the other to a hexagonal. Copper belongs

* This is too complicated to produce in a figure.

to the former class ; silver has lately been shown to possess the same structure ; no doubt gold has the same form. Bismuth and antimony were shown more than a year ago to possess a structure somewhat like that of the diamond. Recently it has been shown that the difference consists in the fact that the little tetrahedron of which we spoke in the case of the diamond is not quite regular, and that the atom which lies within is not at the centre but is pushed along the axis of symmetry towards the corner through which the axis runs.

Every atom in antimony or bismuth has, as it were, a great affinity to one neighbour and a lesser affinity in equal amounts to other three.

The study of iron crystals has hardly been begun. Perhaps at some future date I may have the opportunity of telling you more about them. You will understand that the circumstances of the time have put a stop to the ordinary development of these researches.

In conclusion, let me say that here are only the beginnings of a new science. I trust it will not be very long before we are able to describe the internal constitution of a number of the most important and prevalent crystalline forms, and that we shall be able to explain the inner meaning of allotropic forms. Indeed we have already made the beginnings of progress in this direction ; and, speaking more generally, we see dimly many directions in which the work will lead us to interesting and useful results. The methods are wholly new and open out to us fields into which we have never been before.

When once more we are able to prosecute these researches in peace, we trust that we shall find our hopes fulfilled and shall be able to build up on this foundation a structure which will be **important** both to pure and applied science.

[Of the numerous models and lantern slides used to illustrate the lecture figures 1-6 are reproductions, and for permission to reproduce these in the *Journal* acknowledgment is due to the Royal Society, the Chemical Society, and Messrs. G. Bell and Sons. — Ed.]

AUTUMN MEETING.

THE EIGHTH ANNUAL AUTUMN MEETING of the Institute of Metals was held in the Hall of the Chemical Society, Burlington House, Piccadilly, W., on Wednesday, September 20, 1916, commencing at 4.0 P.M., the President, Sir George Beilby, LL.D., F.R.S., in the Chair.

The SECRETARY (Mr. G. Shaw Scott, M.Sc.) read the Minutes of the last General Meeting, which were confirmed.

COUNCIL FOR 1917.

The SECRETARY, in accordance with the articles of association, presented, on behalf of the Council, the following list of Members nominated by the Council for election on the Council in 1917 :—

President.

* Sir GEORGE BEILBY, LL.D., F.R.S.

Vice-Presidents.

(Two to be elected.)

* Mr. L. SUMNER, M.Sc.

* Professor T. TURNER, M.Sc., A.R.S.M.

Members of Council.

* Mr. W. H. ALLEN.

* Mr. A. CLEGHORN.

* Mr. J. DEWRANCE.

† Mr. S. EVERED.

* Mr. A. PHILIP, B.Sc., A.R.S.M.

The PRESIDENT enquired whether any member desired to make any further nominations.

No further nominations being forthcoming, the PRESIDENT declared that the names the Secretary had read would go forward for election.

* Retires, eligible for re-election.

† New nomination.

ELECTION OF MEMBERS.

The SECRETARY read the following list of names of candidates who had been duly elected as a result of the ballot concluded on 20th September, 1916 :—

NAME.	ADDRESS.	QUALIFICATIONS.	PROPOSERS.
Andrews, Joseph C.	123 Vine Street, New Britain, Conn., U.S.A.	Chemical Engineer	F. P. Gilligan. W. B. Price. A. E. Seaton.
Brown, Percy	David Brown & Sons, (Hudd.), Lt., Huddersfield	Engineer, Joint Managing Director	J. P. Bedson. L. Sumner. E. L. Rhead.
Carter, Frederic E., Dr. Ing., B.Sc.	Baker Platinum Wks., Newark, N.J., U.S.A.	Physical Metallurgist	A. Stansfield. Sir G. T. Beilby. H. C. H. Carpenter.
Child, Walter Haydn	David Brown & Sons, (Hudd.), Ltd., Huddersfield	Engineering Director	J. P. Bedson. L. Sumner. E. L. Rhead.
Couves, Harry Augustus	Newcastle Electric Supply Co., Royal Exchange Bldgs., Newcastle-on-Tyne	Engineer	G. B. Hunter. G. Stoney. A. C. Michie.
Hatfield, William Herbert, D. Met.	15 Oakdale Road, Sheffield	Metallurgist	W. Rosenhain. H. C. H. Carpenter. T. Turner.
Hinchliffe, Harry	6 Newton Street, Rotherham	Brass worker and Engineer	T. Baker. F. M. Watson. G. B. Brook.
Houston, Robert Henry Pollett	H. L. Raphael's Refinery, Limehouse, E.	Engineer Manager, Aluminium Department	W. M. Morrison. Sir C. A. Parsons. C. O. Bannister.
Ishikawa, Eng. Lieut.-Com. Tokiji	Imperial Japanese Navy, Broadway Court, Westminster	Chief Naval Constructor	C. H. Desch. K. Tawara. W. Rosenhain.
Le Bas, Edward	Dock house, Billiter Street, E.C.	Owner & Chairman, National Alloys, Limited	F. M. Garnham. J. C. Garnham. J. W. Earle.
MacWhirter, James	Wm. Beardmore & Co. Ltd., Parkhead Forge, Glasgow	Chemist	W. Onyon. M. Paul. J. Steven.
Norman, Philip William	72 Waldegrave Road, Teddington, Middlesex	Engineer, Aluminium Plant and Vessel Co.	R. Seligman. A. L. Davis. A. Jacob.
Rutherford, Henry	Venesta Limited, 1 Great Tower Street, E.C.	Director	H. L. Lancaster. G. D. Cowan. G. H. Quirk.

NAME.	ADDRESS.	QUALIFICATIONS.	PROPOSERS.
Smalley, Oliver	26 Wingrove Road, Newcastle-on-Tyne	Metallurgist, Sir W.G. Armstrong, Whitworth & Co.	W. Gemmell. H. Dunford Smith. J. T. Dunn.
Smith, Harold (Student)	170 Walmgate, York	Automobile and Mechanical En- gineer	H.C.H. Carpenter. Sir G. T. Beilby. J. T. Milton.
Tresidder, Alfred Henry	34 Osterley Park, View Road, Hanwell, W.	Foreman Moulder	R. Seligman. A. L. Davis.
Vosmaer, Alex- ander	Koningen Wil- helminalaan 140, The Hague, Holland	Chemical and Electrical En- gineer	W. M. Morrison. R. A. Hadfield. A. K. Huntington.
Williams, Robert Seaton, Ph.D., B.S.	Mass. Inst. of Tech., Boston, Mass., U.S.A.	Assist. Prof. of Chemistry, In- structor in Metallography	Sir G. T. Beilby. H. Fay. A. D. Little. W. M. Corse.

PAPERS.

The SECRETARY reported that the following papers had been accepted by the Council for presentation at that meeting and that they would be taken in the undermentioned order :—

1. Mr. C. H. MATHEWSON and Mr. E. M. THALHEIMER (Yale University, U.S.A.), on "The Annealing of Arsenical Brass containing 61 and 62.5 per cent. of Copper. A Study of the Structure and Properties Developed by varying the Rate of Cooling within the Transformation Range."
2. Dr. W. H. HELDERMAN (Utrecht University, Holland), on "The Allotropy of Silver."
3. Mr. ERNEST A. SMITH, A.R.S.M. (Sheffield), on "The Development of the Spelter Industry."

Also the following Note :—

Mr. W. R. INGALLS (New York, U.S.A.), on "Cadmium in Spelter."

In the absence of the Authors abstracts of Papers No. 1 and No. 2 were presented, respectively, by Dr. W. ROSENHAIN, F.R.S., and Sir THOMAS ROSE, D.Sc. The papers were then read and discussed.

The PRESIDENT proposed a hearty vote of thanks to the Authors, and to the presenters, of the papers, the proceedings being adjourned at 6.15 P.M.

The evening session commenced at 8.0 P.M. with the reading, by the Author, of Paper No. 3. This was subsequently discussed, and afterwards the Note was taken as read.

A hearty vote of thanks was accorded, on the motion of the President, to the Authors of the paper and the Note, respectively.

The proceedings terminated at 10.0 o'clock P.M. with a vote of thanks to the Chemical Society for permitting the use of the Society's rooms for the purpose of holding the meeting.

THE ANNEALING OF ARSENICAL BRASS CONTAINING 61 AND 62.5 PER CENT. OF COPPER. A STUDY OF THE STRUCTURE AND PROPERTIES DEVELOPED BY VARYING THE RATE OF COOLING WITH- IN THE TRANSFORMATION RANGE.*

*Metallographic Communication from the Hammond Laboratory of
the Sheffield Scientific School, Yale University.*

BY C. H. MATHEWSON AND E. M. THALHEIMER.

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I. OBJECT OF THE INVESTIGATION.

DURING the summer of 1914 we were called upon to make tests for the purpose of selecting a brass mixture based upon the use of Copper Range copper—a 'Lake' brand containing about 0.3 per cent. of arsenic—and of specifying forms of heat treatment which would give satisfaction in the manufacture of heavy tube.

The particular process for which this material was intended

* Read at the Annual Autumn Meeting, London, September 20, 1916.

consists essentially in hot-rolling a thick cake to a circular disc about one-half inch thick, annealing and then cupping the disc, after which tube is produced by a number of closing in and drawing operations, each preceded by annealing treatment. It is thus apparent that the material must be adapted to hot working and, in addition, must possess a high order of ductility when cold, so that it may flow freely between the punch and die.

As a result of preliminary tests on several mixtures, we recommended material containing 62.5 per cent. of copper, which, as ordinarily cast from Copper Range copper, would contain not more than 0.16 per cent. of arsenic. Using a high grade of spelter, there would be no difficulty in hot-rolling brass containing a considerably higher percentage of copper than this. It is our impression that the hot-rolling properties of these alloys are largely dependent upon the lead-content and the amount of the Beta constituent present at the rolling heat. Carpenter * shows a photo which indicates that lead dissolves rather freely in the Beta constituent and F. Johnson † points out that this condition is probably responsible for the neutral bearing of lead on the hot-rolling properties of Muntz metal. Precise information with respect to the solubility of lead in the Beta constituent would be of great value to brass metallurgists and will doubtless be forthcoming at no very remote date.

Whatever the merits of this contention, it is well known that brass of very ordinary quality containing up to some 64 per cent. of copper can be successfully hot-rolled.

When we compare the ductilities of annealed brasses containing 62.5 and 60 per cent. of copper (ordinary Muntz metal), we find a pronounced difference in favour of the former mixture. Guillet's ‡ comparatively recent tests show that a decrease of 1 per cent. in copper-content within the range 60–65 per cent. of copper brings about a decrease of some five percentage units of elongation, measured in 100 millimetres. Our own tests show a more pronounced effect in this direction. Thus, where high ductility is required in a hot-rolling mixture for subsequent process purposes,

* "The Effect of Other Metals on the Structure of the Beta Constituent in Copper-Zinc Alloys," H. C. H. Carpenter, *Journal of the Institute of Metals*, No. 2, 1912, vol. viii. Plate XV.

† Discussion of above paper, p. 83.

‡ "Nouvelles Recherches sur les Alliages de Cuivre et de Zinc," M. L. Guillet, *Revue de Métallurgie*, 1914, vol. xi. p. 1113.

it is well to raise the copper-content within reasonable limits and to keep the mixtures under good control by analysis.

Following the preliminary tests mentioned above, a manufacturing test was undertaken and six cakes of the following composition were carried through the above-mentioned process with entire success :

	Copper Per Cent.	Arsenic Per Cent.	Lead Per Cent.	Iron Per Cent.
No. 1	62.12	0.158	0.057	0.062
No. 2	62.14	0.147	0.054	0.061
No. 3	62.17	0.140	0.053	0.104
No. 4	62.43	0.128	0.057	0.065
No. 5	62.64	0.134	0.059	0.059
No. 6	62.64	0.133	0.055	0.050

These tests are cited merely as an example of mill work involving the use of brass containing from 62.1 to 62.6 per cent. of copper and rather more arsenic than is considered acceptable in some quarters, which in the opinion of the authors has demonstrated that arsenical brass of this type will meet severe hot- and cold-working requirements.

The main purpose of this paper is to present the results of laboratory tests which are the outgrowth of the preliminary tests mentioned in the above connection and which show comparisons between the properties of brass containing (1) 62.5 per cent. of copper and very little arsenic (0.024 per cent.), (2) 62.5 per cent. of copper and considerable arsenic (0.120 per cent.), and (3) 61 per cent. of copper and considerable arsenic (0.139 per cent.) after different forms of heat treatment.

In planning a set of comparative experiments intended to develop points of difference between a special alloy and a standard alloy, it is well to start with an understanding of the characteristics of the standard alloy. It is clear that the properties of a standard alloy of the Muntz metal type will depend primarily upon the relative quantities of the Alpha and Beta constituents of the alloy, and these quantities will depend upon the heat treatment, i.e. upon the temperature and time of annealing and the subsequent rate of cooling.

In the ordinary brass mill, metal is annealed for half an hour or so after coming to the heat of the furnace and is then brought out to cool on the floor. The temperatures involved and the load factor will determine the rate of cooling. Some tests

made in the mill during these experiments showed that, under the prevailing annealing conditions, the metal cooled at an average rate not far from 20° per minute in the upper range (above 350°).

It was therefore desirable to know what effect this and neighbouring rates of cooling (above and below 20° per minute) would have on the properties of ordinary Muntz metal. Unfortunately, however, most authors have specified rates of cooling only in general terms, e.g. air cooling, furnace cooling, &c. Moreover, previous investigations on Muntz metal seem to have dealt with conditions rather widely removed from those under present consideration. For example, Bengough and Hudson * tested slowly cooled (from 4° to 5° C. per minute), air cooled, and quenched specimens, mainly after half-hour and seven-hour annealing periods. Their results are chiefly valuable in indicating the effect of structural rearrangements, as related to the period of annealing, on the properties of slowly and rapidly cooled metal. Again, Stead and Steadman † have devoted particular attention to very long periods of annealing (48 hours or more) with subsequent air cooling, or quenching in water. Finally, other authors, notably Guillet, ‡ have investigated the effect of varying the copper-content in connection with some particular form of heat treatment.

Thus it appears that the results to be given in the present paper deal with conditions somewhat different from those reported in other published papers. While the rate of cooling in ordinary annealing practice is variable throughout the entire range, we determined to make use of linear rates of cooling in the laboratory experiments, as these seem to afford the only fixed basis of comparison. Furthermore, in all of our experiments, 450° C. was taken as the lower limit of cooling at a given rate, and the properties of the metal at this point were fixed by quenching. Experiments by Philip Davidson in this laboratory indicate that the absorption of metastable Beta below 450° C. is very slow and that there is little possibility of bringing about a change in properties by varying the rate of cooling below this temperature. Thus,

* "Heat Treatment of Copper-Zinc Alloys," G. D. Bengough and O. F. Hudson, *Journal of the Society of Chemical Industry*, 1908, vol. xxvii, pp. 43-52 and 654-658.

† "Muntz Metal: Correlation of Composition, Structure, Treatment, etc.," J. E. Stead and H. G. A. Steadman, *Journal of the Institute of Metals*, No. 1, 1914, vol. xi, pp. 119-150.

‡ *Loc. cit.*, p. 2.

a quantity of metastable Beta developed by quenching common high brass at 800° C. is absorbed in a brief period of minutes by reheating at 600° C. ; in a long period of minutes by reheating at 550° C. ; but only after a long period of hours by reheating at 450° C. ; and after a period of days by reheating at 400° C.

II. CHARACTER AND PREVIOUS HISTORY OF THE MATERIAL USED.

Three kinds of material were used in this investigation. As the principal object was to study the comparative properties of arsenical and non-arsenical brass containing 62·5 per cent. of copper, we were particularly fortunate in securing two mixtures containing very nearly the same content of copper and of ordinary impurities ; one from Copper Range copper (containing arsenic) and Glendale refined spelter ; and the other from electrolytic copper and the same spelter. The remaining mixture was made from Copper Range copper and thus carried arsenic, but its copper-content was about one and one-half percentage units below that of the other mixtures. Although we had no mixture of similar composition made from electrolytic copper, it was decided to treat this mixture along with the others for the purpose of obtaining certain comparisons from the standpoint of variation in copper-content.

The following table shows the composition and the numerical designation of the three alloys specified.

TABLE I.—*Composition and Designation of the Three Mixtures Used in Ensuing Tests.*

Mixture No.	Per Cent. of Copper.	Per Cent. of Arsenic.	Per Cent. of Lead.	Per Cent. of Iron.
I	62·41	0·024	0·022	0·03
II	61·07	0·139	0·086	0·03
III	62·49	0·120	0·017	0·03

It may be observed that Alloys I and III are very nearly identical except for the difference in arsenic-content. It was intended that Alloy I should be practically free from arsenic. Since it was prepared primarily from electrolytic copper and a

high grade of spelter, the small but appreciable arsenic-content reported is probably due to the use of some arsenical scrap in making the mixture. It is clear, however, that the original purpose of the forthcoming tests is not greatly impaired by this unforeseen circumstance, since Alloy III contains five times as much arsenic as Alloy I, and the latter may be regarded as a very pure brass.

The above material came to the laboratory in the form of bars, $14'' \times 1'' \times \frac{1}{2}''$, cut from the hot-rolled discs, previously mentioned, after annealing at red heat with subsequent slow cooling. (Precise data bearing upon this annealing treatment could not be secured.)

A sample very similar in composition to Alloy III was taken after hot-rolling.* The structure of this alloy, which may be considered representative of the hot-rolled structures of Alloys I and III, is shown in Fig. A of Plate I. At this stage, perhaps a third of the alloy is composed of the Beta constituent, which has a banded appearance due to flow in a prevailing direction as the metal passed through the rolls. Neighbouring bands composed of the Alpha constituent show a secondary grain-structure indicative of a final recrystallization during the last stages of the rolling process.

Alloy II, containing a lower percentage of copper, would obviously show a greater proportion of Beta after hot-rolling than Alloys I and III. However, no observations were made on this alloy at this stage.

During annealing, if this takes place at a temperature below that which corresponds to equilibrium between the quantities of Alpha and Beta shown in the hot-rolled metal, there will be an absorption of Beta and, in any case, there will be an absorption of Beta on slow cooling after the anneal.

The extent of this absorption will, of course, depend upon the rate of cooling after the anneal; even with very slow cooling, absorption can hardly be carried beyond the point corresponding to equilibrium quantities of the two constituents at some 400° – 450° C.

In the present case, slow cooling has resulted in marked

* This alloy contained 62.43 per cent. of copper, 0.128 per cent. of arsenic, 0.057 per cent. of lead, and 0.065 per cent. of iron.

absorption, as shown in Figs. B and C of Plate I., representing Alloys III and II, respectively. The structure of Alloy I at this stage cannot be distinguished from that of Alloy III and an additional photo seems unnecessary.

From observations on the actual annealing process and on the behaviour of these alloys under test, we conclude that the proportions of Alpha and Beta present correspond to those required for equilibrium at a temperature in the neighbourhood of 500° C. A glance at the photos shows us that not enough Beta remains in Alloy III (Fig. B) after the anneal to reveal the directional characteristics of the original hot-rolled metal, while in Alloy II (Fig. C) there is still enough Beta present to clearly reveal the banded structure developed by hot rolling.

A number of the bars, whose structural characteristics have just been described, were tested with the following results :

TABLE II.—*Mechanical Properties of the Bars as Received.**

Material No.	Tensile Strength, Lb. per Sq. In.	Percentage Reduction of Area.	Percentage Elongation, 2 Inches.
I	43,825	61.95	71.75
II	51,325	44.95	54.50
III	45,050	63.23	73.25

Following these tests, some preliminary annealing experiments were made on the bars for the purpose of developing a maximum of ductility. In this work, the material was annealed at 550° and 650° C. for one hour and cooled in the furnace to approximately 300° C. at the very slow rate of 2° per minute. Tests were then made with the results shown on p. 25.

It may be noted that this treatment has effected some improvement in the ductility of the material, particularly of Alloy No. II,† but it is chiefly of interest as evidence that the original mill anneal of Alloys I and III, at least, was quite efficient in developing the ductility of these alloys.

* Averages of two tests on each kind of material.

† Examination of the annealed product gave little indication of change in the structure of Alloys I and III, while the Alpha grain of Alloy II has coarsened somewhat after annealing at 550° and considerably after annealing at 650°. In addition, the original banded structure has given place to a network structure in which the separate grains of Alpha are surrounded by meshes of Beta. For want of space these photos are not included in the present collection.

For use in the principal series of tests, to be described later, bars from the above stock were rolled to give two sets of test-strips: (1) strips $10'' \times 1'' \times 0.116'' - 0.073''$, to be tested as rolled to the different gauges, and (2) strips $10'' \times 1'' \times 0.128''$ to be heat treated and tested as described later.

The preparation of these strips was as follows: * All of the

TABLE III.—*Mechanical Properties of the Bars after Preliminary Annealing Treatment Followed by Cooling at a Rate of 2° per Minute.*†

Material No.	Temperature of Anneal.	Tensile Strength, Lb. per Sq. In.	Percentage Reduction of Area.	Percentage Elongation, 2 Inches.
	$^\circ$ C.			
I	550	43,883	62.95	72.83
I	650	45,033	64.88	71.50
II	550	49,617	52.63	61.67
II	650	50,217	54.10	61.83
III	550	44,667	61.17	75.00
III	650	45,850 (two tests)	61.08	73.00

bars were cold-rolled from their original thickness of 0.5 inch to a thickness of 0.258 inch in ten passes, viz.:

- | | | |
|--------------------|--------------------|---------------------|
| (1) 0.500 to 0.461 | (5) 0.409 to 0.375 | (8) 0.326 to 0.303 |
| (2) 0.461 to 0.443 | (6) 0.375 to 0.349 | (9) 0.303 to 0.280 |
| (3) 0.443 to 0.428 | (7) 0.349 to 0.326 | (10) 0.280 to 0.258 |
| (4) 0.428 to 0.409 | | |

Annealing for one hour at 650° C., followed by slow cooling, was specified at this stage. While we have no data as to the temperatures and rate of cooling realized in this mill annealing, photomicrographs were prepared and these indicate, in the light of the forthcoming systematic observations on the effects of heat treatment, that the residual quantities of Beta are such as would be produced by annealing at moderate red heat, followed by cooling at a rate considerably in excess of 5° per minute.

These photomicrographs are shown in Figs. A, B, and C of Plate II. It should be noted that the Alpha grains are surrounded in part by a network of Beta. Subsequent tests have shown that Beta will develop in this form in the present material

* Mill work was done in a neighbouring rolling-mill according to our specifications and under the supervision of their laboratory.

† Averages of three tests on each kind of material.

by annealing at temperatures above some 600°C . and that the network will be completely absorbed by cooling at a rate of 5° per minute, but distinctly retained after cooling at a rate of 20° or more per minute. If these strips were annealed at some temperature considerably in excess of 650°C . (say 750°C .), subsequent cooling must have been faster than 5° per minute, but nevertheless slow, while if they were annealed at 600° to 650°C ., cooling may have occurred at almost any rate in excess of 5° per minute. After this anneal, all of the strips were cold-rolled from the present thickness of 0.258 inch to a thickness of 0.128 inch in the following ten passes.

(1) 0.258 to 0.225	(5) 0.172 to 0.162	(8) 0.147 to 0.141
(2) 0.225 to 0.202	(6) 0.162 to 0.155	(9) 0.141 to 0.133
(3) 0.202 to 0.184	(7) 0.155 to 0.147	(10) 0.133 to 0.128
(4) 0.184 to 0.172		

These strips were divided into two lots, the first of which was annealed under the previous specification (650°C ., followed by slow cooling) for subsequent rolling to a succession of gauges, and the second held in this form for systematic experiments on the effect of heat treatment, to be described in proper sequence. It may be noted that this material has received a final cold reduction by rolling of about 50 per cent. (from 0.258 inch to 0.128 inch) and that all of the ensuing experiments on heat treatment are based upon the use of material in this form.

The anneal given to the first lot of strips is represented by Figs. D, E, and F, of Plate II. Here, cooling must have been slower than in the case of the first anneal (represented by the accompanying photos, Figs. A, B, and C), or the annealing temperature must have been somewhat lower, as no distinct network of Beta can be seen.

The finishing passes received by this lot were graded so as to yield five sets of strips, of different tempers or percentage reductions, as follows :

- (1) From B. and S. wire Gauge No. 8 (0.128") to Gauge No. 9 (0.114") = 1 number hard, or 10.9 per cent. reduction.
- (2) From Gauge No. 8 to No. 9 to No. 10 (0.102") = 2 numbers hard, or 20.3 per cent. reduction.
- (3) From Gauge No. 8 to No. 9 to No. 10 to No. 11 (0.091") = 3 numbers hard, or 28.9 per cent. reduction.
- (4) From Gauge No. 8 to No. 9 to No. 10 to No. 11 to No. 12 (0.081") = 4 numbers hard, or 36.6 per cent. reduction.
- (5) From Gauge No. 8 to No. 9 to No. 10 to No. 11 to No. 12 to No. 13 (0.072") = 5 numbers hard, or 43.8 per cent. reduction.

The above are even numbers according to the Brown and Sharp wire gauge and correspond to the specifications submitted. The exact gauges, as measured on the finished strips, along with the exact reductions figured from these measurements are given in Table IV., p. 28, along with the results of mechanical tests.

III.—DESCRIPTION OF TESTS ON MATERIAL ROLLED TO A SUCCESSION OF GAUGES.

The preparation of test-strips for this part of the work has been described in the preceding section. According to the usual practice, the strips were milled along the edges of a central section for the purpose of obtaining properly located breaks in the tensile test. The original strips were 10 inches long, 1 inch wide and of variable thickness to correspond with the degree of previous reduction by cold-rolling. After milling, the central test-section measured $\frac{3}{4}$ inch in width and $5\frac{3}{4}$ inches in length up to its junction with the end sections (1 inch in width), and this junction was made with a radius of curvature of 1 inch at all four points.

Tensile tests were made in the usual manner with the aid of a Riehle 50,000 lb. universal testing machine. The results, embracing data on the tensile strength, percentage elongation in 2 inches and percentage reduction of area, are assembled in Table IV. and the averaged results shown in the table are plotted in connection with the percentage reduction in area of the strips by rolling, in Fig. 1.

On examining the plotted points representing the reduction of area of Alloys I and III (in Fig. 1), it will be observed that no clear distinction can be made between the two sets of results and, accordingly, only one curve has been drawn in this case. No strips were tested in their initial (soft) condition (corresponding to micrographs D, E, and F of Plate II.). From tests on similar material, however, it is known that the tensile strength of Alloys I and III will be in the neighbourhood of 50,000 lb. per square inch; of Alloy II in the neighbourhood of 56,000 lb.; that the elongation of Alloys I and III will be in the neighbourhood of 70 per cent.; of Alloy II in the neighbourhood of 60 per cent.; and that the reduction of area of Alloys I and III will

TABLE IV.—*Testing Data Showing the Effect of Different Degrees of Reduction by Rolling on the Mechanical Properties.*

Original Thickness of Strips, 0.128".

No. of Test.	Grade * of Material.	Thickness.	Reduction by Rolling, Per Cent.	Tensile Strength, Lb. per Sq. In.	Reduction of Area, Per Cent.	Elongation per Cent. in 2 Inches.
1	I	0.116		53,600	54.40	57.50
2	I	0.1155		53,000	54.70	56.00
	Average	0.1158	9.53	53,300	54.55	56.75
3	II	0.1155		59,900	48.20	47.50
4	II	0.1155		59,400	48.00	49.00
	Average	0.1155	9.75	59,650	48.10	48.25
5	III	0.1155		53,000	54.00	61.50
6	III	0.1155		53,000	54.80	59.00
	Average	0.1155	9.75	53,000	54.40	60.25
7	I	0.103		56,900	51.60	48.00
8	I	0.1035		56,800	51.50	48.00
9	I	0.1035		57,200	50.80	45.00
10	I	0.104		57,000	50.80	46.00
	Average	0.1035	19.14	56,975	51.18	46.75
11	II	0.102		66,900	43.80	35.00
12	II	0.102		66,900	43.80	36.00
	Average	0.102	20.25	66,900	43.80	35.50
13	III	0.103		59,100	51.70	52.00
14	III	0.103		59,000	51.70	52.00
	Average	0.103	19.50	59,050	51.70	52.00
15	I	0.092		64,100	49.90	32.00
16	I	0.0915		64,100	49.40	32.00
	Average	0.0918	28.25	64,100	49.65	32.00
17	II	0.091		73,500	40.80	24.00
18	II	0.091		73,600	40.90	24.00
	Average	0.091	28.85	73,550	40.85	24.00
19	III	0.091		65,300	49.90	33.00
20	III	0.091		65,000	50.00	34.00
	Average	0.091	28.85	65,150	49.95	33.50
21	I	0.0815		71,000	40.90	20.00
22	I	0.0815		70,800	40.85	20.50
	Average	0.0815	36.33	70,900	40.88	20.25
23	II	0.082		79,300	32.70	16.00
24	II	0.082		79,400	33.20	17.00
	Average	0.082	35.90	79,350	32.95	16.50
25	III	0.081		72,700	38.50	22.00
26	III	0.081		72,500	38.70	22.00
	Average	0.081	36.65	72,600	38.60	22.00
27	I	0.073		77,000	33.40	12.00
28	I	0.073		77,000	33.10	12.00
	Average	0.073	42.90	77,000	33.25	12.00
29	II	0.074		83,500	27.10	12.00
30	II	0.074		83,800	27.50	14.00
31	II	0.074		83,500	27.90	13.00
32	II	0.074		83,800	27.40	14.00
	Average	0.074	42.20	83,650	27.48	13.25
33	III	0.073		77,400	32.80	13.00
34	III	0.073		77,400	32.80	13.00
	Average	0.073	42.90	77,400	32.80	13.00

* Composition of Alloys:

No.	Per Cent. of Copper.	Per Cent. of Arsenic.	Per Cent. of Lead.	Per Cent. of Iron.	Per Cent. of Zinc (by Difference).
I	62.41	0.024	0.022	0.03	37.514
II	61.07	0.139	0.086	0.03	38.675
III	62.49	0.120	0.017	0.03	37.343

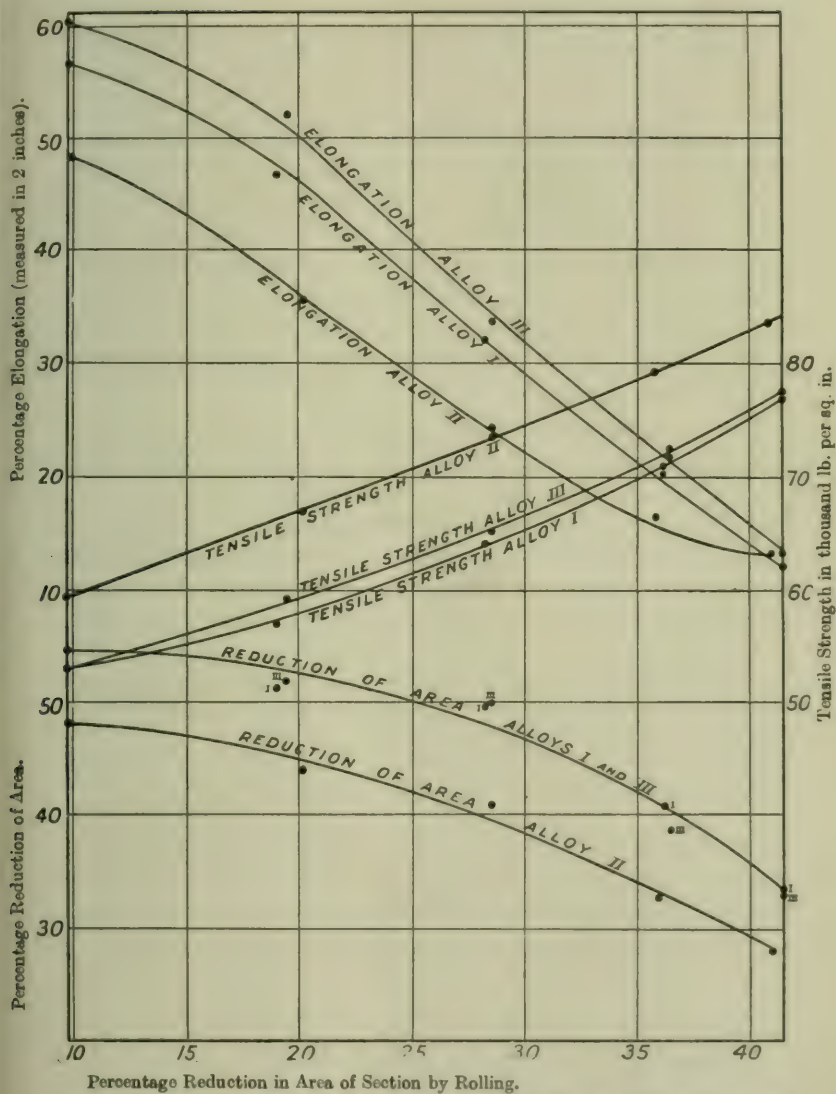


FIG. 1.—Effects of Rolling to a Succession of Gauges on the Mechanical Properties of Alloys I, II, and III.

be in the neighbourhood of 60 per cent.; of Alloy II in the neighbourhood of 54 per cent.

It is particularly noticeable that while the percentage elongation (measured in 2 inches) lies some ten units above the percentage reduction of area of a given alloy in the annealed condition, both fall to about the same value after a comparatively moderate cold reduction of 10 or 15 per cent. At the extreme reduction of some 40 per cent., the elongation of all three alloys has fallen to some 12 to 13 per cent., while the reduction of area has fallen to some 32 per cent. in the case of Alloys I and III, and to 27 per cent. in the case of Alloy II. Thus, the drop in elongation is much more pronounced than the drop in reduction of area, as the alloys are rolled from one gauge to another throughout the present range.

This behaviour is not peculiar to this particular material, but may also be seen in copper * and iron or soft steel † and is doubtless a general requirement for ductile material.‡

As will be shown in the following sections of this paper, the annealed arsenical alloy containing 62.5 per cent. of copper consistently shows higher elongation and higher tensile strength than the annealed non-arsenical alloy of the same copper-content. The present tests show that this superiority of the arsenical alloy over the non-arsenical alloy is maintained throughout the range of cold-reductions (10 to 40 per cent.) shown. Thus, the elongation and tensile strength curves of Alloy III lie above the corresponding curves of Alloy I, although the difference is slight in the case of tensile strength, and an initially pronounced difference in the case of elongation becomes less marked as the percentage reduction by rolling increases. The (arsenical) alloy containing 61 per cent. of copper, viz., Alloy II, is initially much stronger and far less ductile than either of the alloys containing 62.5 per cent. of copper. The difference in strength remains

* "Comparisons between Electrolytic Copper and Two Varieties of Arsenical Lake Copper with respect to Strength and Ductility in Cold-Worked and Annealed Test-Strips," C. H. Mathewson and E. M. Thalheimer, *Bulletin of the American Institute of Mining Engineers* (in press).

† "Über den Einfluss der Kaltformgebung auf die Eigenschaften von Eisen und Stahl," P. Goerens, *Ferrum*, 1912, vol. x. pp. 65-81.

‡ This of course means that, after a moderate reduction by rolling, the stretch is localized near the break and that considerable "necking" takes place. If the stretch were equally distributed along the entire test-section, the percentage elongation would always exceed the percentage reduction of area and the numerical ratio between the two would be that of the final to the original length of the test-section.

about the same throughout the rolling range. The same is true of the reduction of area, but the elongation values of all three alloys converge as the reduction by rolling increases, and become practically coincident at a reduction of 42 to 43 per cent.

IV. DESCRIPTION OF TESTS ON HEAT-TREATED MATERIAL.

(a) Forms of Heat Treatment adopted in Two Principal Series of Tests.

These experiments were planned with the idea of acquiring some definite knowledge of such variations in properties and structure of these alloys as might be expected to occur in the ordinary mill-handling of the material. At the outset, we were forced to set certain limitations to the character and variety of the work, as time could not be taken for the large number of experiments which might be outlined in this connection. In general, this problem calls for information in two principal directions: (1) with respect to the structure developed by annealing at a variety of temperatures and the properties of alloys in which this structure is retained; and (2) with respect to the changes in structure which may take place under different cooling conditions and the associated changes in properties.

In order to secure results of the first type, we decided to anneal the three kinds of material at intervals of 50° throughout a temperature range of 450° to 750° C. and thereupon quench the alloys in water. These tests should serve to develop the structures produced at any ordinary annealing heat and fix them permanently for observation and test. The upper experimental limit was placed at 750° C. because this represents a temperature commonly reached in the dead-soft annealing of Alpha brass. Although we think that brass of the Muntz metal type should be annealed at much lower temperatures, this is not always done, and variations within the stated limits may certainly be expected. We chose an annealing period of fifteen minutes, commencing from the time the strips attained the desired temperature. Our choice in this respect was guided by the fact that when a load is annealed for a half-hour in the mill, as is a common custom, the metal is quite likely to anneal at full heat for some 15 minutes, and it is our opinion that equilibrium quantities of Alpha and Beta are

developed in a 15-minute period of anneal at temperatures above 600° C. It may be added that our later experiments on the reabsorption of Beta during cooling were based upon a previous anneal at 700° C., and a 15-minute period certainly suffices for equilibrium in this case. While an annealing period of 15 minutes probably suffices in most cases to develop equilibrium-quantities of the two constituents, it is quite certain that the distribution of the constituents (size and arrangement of the component particles) will be affected by further exposure at the given temperature. In the time available, however, we could not extend the experiments in this direction.

It is much more difficult to plan a limited number of experiments of the second type mentioned above. In the first place, an initial temperature must be chosen from which cooling is to begin, and, in the second place, definite rates and methods of cooling must be selected. Here, we adopted an annealing temperature of 700° C. and rates of 5° , 20° , 50° , and 100° C. per minute. The annealing temperature was selected with the knowledge that a considerable quantity of Beta would develop at 700° C.; that the alloys would frequently be heated to this temperature and less frequently to higher temperatures in the mill; and that heating to materially lower temperatures, say 600° C., would develop so little Beta that the subsequent rate of cooling would have comparatively little effect on the properties of the material. With regard to rates of cooling, it was known from observation that in the mill-treatment of cups and tubes made from this material, an average rate of cooling of 20° per minute frequently prevailed. Thus, the laboratory experiments were based upon this rate; a considerably slower rate (5° per minute); a considerably faster rate (50° per minute); and a still faster rate (100° per minute), in addition to the original quenching rate.

An improvement in ductility would be effected by cooling at a still slower rate than 5° per minute, but at the 5° rate it would take 50 minutes for the material to cool from 700° C. to 450° C., and even this may be considered prohibitive where one load must leave the floor when another enters the furnace. At the rates mentioned, very little change in structure or properties takes place on cooling below 450° C.; consequently, this was taken as a lower limit and the strips were quenched at this point. All rates of

cooling in the laboratory work were made linear by cooling in an electric furnace whose temperature could be controlled by outside resistances. While linear rates of cooling do not prevail in ordinary annealing work, such rates afford the best basis of comparison and study.

In order that a thorough understanding of the forms of heat treatment adopted in the two principal series of tests may be reached, tabulated outlines are given. Table V. shows data

TABLE V.—*First Series of Tests. Metal annealed 15 Minutes at various Temperatures and Quenched in Water.*

Material No. (Duplicate Strips).	Annealing and Quenching Temperature.	Preheating Period in Minutes.
	C.	
I	450	16
II	450	16
III	450	16
I	500	14
II	500	14
III	500	14
I	550	13
II	550	17
III	550	13
I	600	14
II	600	14
III	600	14
I	650	16
II	650	17
III	650	16
I	700	16
II	700	16
III	700	16
I	750	16
II	750	16
III	750	16

pertaining to the temperature and time of annealing each furnace load of two test-strips in the *First Series of Tests*. It will be noted that the strips were quenched in all cases after annealing for a period of 15 minutes at the desired temperature and that it required from 13 to 17 minutes to bring the metal up to this temperature. Thus, the metal was annealed in the ordinary sense for a period of about 30 minutes. (The testing data

associated with this form of heat treatment are given in a later section in Table VII.).

Table VI. shows data pertaining to the temperature and time of annealing and the rate of cooling previous to quenching each

TABLE VI.—*Second Series of Tests. Annealing Temperature, 700° C. Annealing Period, 15 Minutes. Material cooled at different rates after annealing and quenched at different Temperatures throughout the Cooling Range.*

Material No. (Duplicate Strips).	Quenching Temperature.	Preheating Period in Annealing at 700° C. Previous to Cooling at a Rate of			
		5° C. per Minute.	20° C. per Minute.	50° C. per Minute.	100° C. per Minute.
I	°C. 650	12	11	12	12
II	650	13	12	12	12
III	650	13	11	12	12
I	600	12	12	12	12
II	600	13	12	12	11
III	600	11	12	11	12
I	550	13	12	12	11
II	550	12	12	13	11
III	550	13	12	12	11
I	500	13	11	12	12
II	500	13	12	12	12
III	500	12	11	12	12
I	450	13	13	12	12
II	450	12	12	12	11
III	450	12	12	12	12

furnace load of two test-strips in the *Second Series of Tests*. While it would be desirable to anneal all of the strips which require cooling at the same rate in one load, and then quench each pair of duplicate strips at different temperature stages during cooling, this could not be done in a laboratory furnace of small capacity and each pair of strips was annealed and cooled separately. There was no difficulty in duplicating the temperatures within several degrees; the individual preheating periods are very similar, as may be seen in this table; and the average rate of cooling realized in one test was closely duplicated in another, except in the case of the 100° rate, as may be seen from the data

which, in this case, have been tabulated along with the results of mechanical tests. (Tables VIII. and XI. inclusive.)

(b) Methods and Apparatus.

Since the two principal series of tests outlined in the preceding section have involved quenching after annealing or after a certain period of cooling at a given rate, it seems necessary to devote some space to a description of the methods used in this part of the work.

The annealing furnace used in these experiments was of the rectangular, box-shaped type, containing an alundum tube 18 inches long and $1\frac{1}{2}$ inch in inside diameter, electrically heated by means of an evenly spaced winding of "Nichrome" ribbon. The heat capacity of the furnace was raised by filling-in the space between the outside of the tube and the sides of the furnace box with granular fireclay, whereby the tube was rendered comparatively immune from temperature fluctuations due to outside influences. Furthermore, it was possible by using false inner V-shaped sides of sheet iron to constrict the filling from the ends towards the centre of the tube so that the normal flow of heat from the central region of the tube might be increased and made to compare with the rapid flow from the unprotected ends.

This arrangement was used in annealing the strips (First Series of Tests), which were subsequently cooled outside of the furnace, i.e., by quenching. In these experiments, the variation of temperature along the central 10 inches of the tube, corresponding to the full length of the enclosed test-strip, was consistently less than 10° .

In annealing the strips which were subsequently cooled in the furnace tube at an established rate of 5° , 20° , 50° , or 100° per minute, the fireclay filling was removed, as, otherwise, the cooling could not be conducted at a sufficiently rapid rate. Due to this removal of the filling, the difference between the maximum and minimum temperatures along 10 inches of the central portion of the tube was raised from 10° to some 30° —a disadvantage which could not well be avoided. The amount of current required to heat the furnace to the desired temperature was increased under these conditions, permitting far better regula-

tion throughout the entire range of cooling. By decreasing the amount of current supplied to the furnace by a definite quantity at stated intervals of time, it was possible to obtain a rather uniform rate of cooling of 5° , 20° , or 50° per minute, as the occasion required. The necessary details of current regulation, &c., were ascertained by a number of preliminary experiments. Much difficulty was experienced in realizing the last rate mentioned, viz., 100° per minute, as in this case the furnace tube had to be cooled in the open air with the aid of an air-blast. Here, the average rates of cooling, as indicated in Table XI., varied from 86° to 110° per minute. The detail of this part of the work was as follows: The annealing tube was taken out of the furnace box and mounted on supports at each end. In heating the tube, it was necessary to make use of a removable asbestos cover (to prevent rapid radiation). At the beginning of the cooling period this cover was removed and a stream of compressed air was directed upon the tube. In order to obtain as uniform cooling as possible along the full length of the tube, the stream of air was played backwards and forwards from end to end, an operation which is not susceptible to very accurate control.

There are several automatic regulating devices on the market designed to give straight line heating or cooling curves. Most of these are operated by means of a motor geared to a rheostat which is arranged to cut out a definite amount of current at definite intervals of time. Since the (D.C.) current delivered to our laboratory fluctuates continually, due to intermittent overloading of the line, the above type of controlling device could not be used in the present work. Burgess * has devised a salt-water rheostat by means of which the current is varied automatically so as to give the desired rate of cooling. This affords an excellent method of furnace control, but since it must be operated on alternating current in order to avoid polarization and electrolysis, no use could be made of it in the present connection.

In all of the annealing work, the test-pieces, milled according to specifications previously given, were placed edge to edge in the annealing furnace so as to form a V, and brought up to the desired temperature by adjustment of the external resistance. The hot junction of the thermocouple was placed near the end

* *Bulletin No. 213, Bureau of Standards, p. 337.*

of this V. The temperature was measured by means of platinum-platinum-rhodium thermocouple and a Siemens and Halske galvanometer of high internal resistance. This apparatus was standardized against the freezing points of "Kahlbaum" tin, zinc, antimony, and silver, with the cold junction maintained at 20° C. After completing the annealing work, the thermocouple was restandardized against the freezing point of zinc, which operation showed that constancy had been maintained within 4° C. It is probable that in all of the annealing work the accuracy of the temperature measurements was within 10° C.

All of the quenchings, whether directly after annealing or in the midst of a given process of cooling, were effected by fastening wires into holes drilled at the ends of the duplicate strips, and rapidly pulling these strips out of the furnace into a pan of water maintained at 20° C.

In order to give a clear idea of the methods used in performing the annealing work, these methods will be described in detail for a given operation. The other annealings (of the corresponding set) were carried out in precisely the same manner.

In the series of experiments which required strips to be quenched after annealing at a given temperature, the furnace was brought up to the desired temperature, say 750° C., and the two test-strips with wires fastened to the ends were run into the central 10 inches of the tube so as to form a V. The thermocouple was then placed within the V, near the end, and the temperature noted at frequent intervals. As soon as the temperature had reached 750° C., a record was made of the total elapsed time, and this is termed the preheating period in the tables. This temperature was now maintained as accurately as possible for fifteen minutes, after which the strips were withdrawn from the furnace tube by means of the attached wires and quenched in the water-bath.

In the case of the metal cooled at 5° C. per minute and quenched at intervals during the cooling period, the strips were placed in the annealing furnace at 700° C. in the same manner as in the case of the previous set. The preheating period was obtained in the same manner, and the bars were also annealed for 15 minutes. In order to cool the metal at the rate of 5° C. per minute to 450° C., for example, the current was reduced

by 0.5 of an ampere every five minutes and the temperature noted every two minutes until 450°C. was reached. The bars were then rapidly withdrawn from the furnace and quenched as previously described. Similar operations were carried out in the case of strips cooled to the various temperatures, i.e., 650° , 600° , 550° , 500° , and 450°C. , and at the various rates, viz., 5° , 20° , 50° , and 100°C. per minute, except that in the case of the more rapid rates of cooling the current was reduced by larger and more variable amounts than before.

After heat treatment, the bars were tested in a 50,000 lb. Riehle Testing Machine and the elongation, ultimate tensile strength, and reduction of area calculated from appropriate data. Of these tests, the reduction in area is the least accurate, owing to the difficulty in getting good measurements on the thin strips used.

For microscopic examination, pieces $\frac{1}{2}$ inch long were cut from the ends of the heat-treated test-strips. These pieces are not entirely representative of the test-section itself, on account of the slight variation in temperature along the strip during the annealing operation. It is, however, impossible to use the central portion of the strip for this purpose, as it must be pulled in the machine and thereafter possesses no value in the present connection.

The above specimens were roughly polished on three blocks covered with emery cloth increasing in fineness from the first to the third block. After the preliminary polishing, the material was finally polished wet on four revolving discs carrying successively finer grades of elutriated emery. In order to develop the Alpha structure, the polished surfaces were first etched with concentrated ammonia to which a little hydrogen peroxide was added. Finally, a light wash of acid ferric chloride solution was used to darken the Beta constituent.

(c) Results obtained in the First Series of Tests.

Table VII. and the corresponding curves, shown in Fig. 2, illustrate the effect of annealing strips for 15 minutes at temperatures ranging from 450° to 750°C. , followed by rapid quenching in water. In these and the following experiments, treatments were not conducted at temperatures lower than 450°C. ,

TABLE VII.—*Testing Data Showing Effect of Quenching at Indicated Temperatures on Mechanical Properties. Annealing Period Previous to Quenching, 15 Minutes.*

No. of Test.	Grade* of Material.	Quenching Temperature. ° C.	Tensile Strength, Lb. per Sq. In.	Reduction of Area per Cent.	Elongation per Cent. in 2 Inches.
35	I	450	52,300	54.70	61.00
36	I	450	52,100	54.90	62.50
		Average	52,200	54.80	61.75
37	II	450	60,400	48.90	50.00
38	II	450	61,400	49.30	51.50
		Average	60,900	49.10	50.75
39	III	450	56,400	52.30	62.00
40	III	450	56,800	52.00	60.50
		Average	56,600	52.15	61.25
41	I	500	50,100	56.20	67.00
42	I	500	50,500	55.90	69.00
		Average	50,300	56.05	68.00
43	II	500	58,400	49.60	59.00
44	II	500	58,400	49.40	55.00
		Average	58,400	49.50	57.00
45	III	500	51,700	54.50	70.00
46	III	500	52,100	54.80	70.00
		Average	51,900	54.65	70.00
47	I	550	48,700	58.00	74.50
48	I	550	47,900	58.40	74.00
		Average	48,300	58.20	74.25
49	II	550	56,100	51.10	62.00
50	II	550	55,800	50.50	62.50
		Average	55,950	50.80	62.25
51	III	550	49,200	57.20	80.00
52	III	550	49,400	55.90	75.00
		Average	49,300	56.55	77.50
53	I	600	50,000	56.70	68.50
54	I	600	48,000	56.20	72.00
		Average	49,000	56.45	70.25
55	II	600	57,900	46.80	58.50
56	II	600	57,500	47.50	58.00
		Average	57,700	47.15	58.25
57	III	600	49,000	55.80	74.00
58	III	600	49,600	55.60	74.50
		Average	49,300	55.70	74.25
59	I	650	51,500	55.70	67.00
60	I	650	51,400	56.00	67.50
		Average	51,450	55.85	67.25
61	II	650	59,800	30.80	53.00
62	II	650	59,000	31.10	53.50
		Average	59,400	30.95	53.25
63	III	650	52,000	55.60	68.00
64	III	650	51,600	55.50	66.50
		Average	51,800	55.55	67.25
65	I	700	53,000	54.40	59.00
66	I	700	52,500	54.40	60.50
67	I	700	53,600	54.30	60.50
68	I	700	53,600	54.00	60.00
		Average	53,175	54.28	60.00

* See footnote on p. 40.

TABLE VII.- *continued.*

No of Test.	Grade* of Material.	Quenching Temperature, ° C.	Tensile Strength, Lb. per Sq. In.	Reduction of Area per Cent.	Elongation per Cent. in 2 Inches.
69	II	700	61,400	29.90	49.50
70	II	700	62,000	30.00	50.00
71	II	700	61,000	31.60	50.00
72	II	700	61,400	31.40	45.00
		Average	61,450	30.73	48.63
73	III	700	54,400	41.00	62.50
74	III	700	54,500	41.00	62.50
		Average	54,450	41.00	62.50
75	I	750	55,800	54.00	52.00
76	I	750	55,900	53.90	52.00
		Average	55,850	53.95	52.00
77	II	750	63,100	29.30	42.00
78	II	750	63,300	29.40	40.00
		Average	63,200	29.35	41.00
79	III	750	56,600	39.10	53.00
80	III	750	56,900	38.90	55.00
		Average	56,750	39.00	54.00

since it has been shown in the work of this laboratory that changes which take place below this temperature are apparent only after very lengthy periods of exposure (measured in hours).

The ductility, as measured by elongation, rises rapidly in all three alloys from the lowest values at 450° C. to maximum values at 550° C., while the tensile strength drops to a minimum at this temperature. From 550° C. to 750° C. the elongation decreases at about the rate of its previous increase on the other side of the maximum, while the tensile strength increases in much the same manner.

The original properties and the rate of change of properties at the lower annealing temperatures would of course depend upon the degree of cold-working before the annealing. In the present case, all the alloys were cold-worked to a 50 per cent. reduction in area of section. With less severe reductions, there would be a more gradual rise towards the maximum, or fall towards the minimum, in the neighbourhood of 550° C., and with more severe reductions there would be a more rapid rise or fall, respectively.

* Composition of Alloys:

No.	Per Cent. Copper.	Per Cent. Zinc (difference).	Per Cent. Arsenic.	Per Cent. Iron.	Per Cent. Lead.
I	62.41	37.514	0.024	0.03	0.022
II	61.07	38.675	0.139	0.03	0.086
III	62.49	37.343	0.120	0.03	0.017



FIG. 2.—Effects of Annealing and Quenching at Indicated Temperatures.

It should be mentioned that the form of a given annealing curve will depend upon the condition of the metal before annealing, not only with respect to the degree of cold-working, but also with respect to the temperature at which the quantities of Alpha and Beta initially present in the alloy can normally coexist. This is due to the fact that, at the lower annealing temperatures, an excess of Beta above the equilibrium requirement cannot be absorbed in any brief annealing period. In the present case, all alloys had been slowly cooled before the annealing treatment. Consequently, the quantities of Alpha and Beta present in these alloys can normally coexist at a comparatively low temperature, probably in the neighbourhood of 500°C . Up to 500°C ., then, there will be, if anything, slight absorption of Beta and beyond 500°C . there will be separation of Beta. The maximum on the elongation curve, for example, will represent that temperature at which the increase in elongation due to recrystallization and growth of the Alpha grain is neutralized by the decrease in elongation due to separation of Beta. This occurs at about 550°C . in all three alloys. It might occur at higher temperatures in alloys which had been very rapidly cooled, so as to retain a large amount of Beta, before annealing, but hardly at temperatures above some 600°C ., even after brief annealing periods, since metastable Beta is rapidly absorbed at this temperature and the elongation would be raised by absorption of Beta before becoming lowered by a natural separation of Beta.

Of the two 62.5 per cent. alloys, the one made from Copper Range copper (Alloy III) shows greater strength and elongation throughout the range tested than the one made from electrolytic copper (Alloy I). However, the ductility of the latter alloy, as measured by reduction of area, is lower than that of the former, especially after treatment at 700° and 750°C . If we base our judgment on the tensile strength and elongation values alone, it appears that the Copper Range metal is superior to the electrolytic metal.

The marked drop in the elongation of Alloy III between 650° and 700°C . (from 56 to 41 per cent.) is striking in comparison with the slight drop in the elongation of Alloy I between these temperatures (56 to 54 per cent.). This difference is not due to a difference in the quantity of Beta, but to a notable difference

in the distribution of the Beta, which may be seen on comparing Fig. A of Plate VIII., representing Alloy I quenched at 700°C. , with Fig. B of the same plate, representing Alloy III quenched at the same temperature. These photos were taken at a low magnification ($\times 22$) and correctly represent the average structures of the alloys. In the case of Alloy I, the Beta which has developed between 650° and 700°C. is rather evenly distributed, as may be seen in Fig. A, while, in the case of Alloy III, this Beta occurs in the form of thin parallel bands, suggestive of a rolled type of structure. It should be pointed out that these bands were not produced directly by rolling, but are due indirectly to the rolling operation.

In brass of this composition a strongly banded form of Beta is developed by hot-rolling, as shown in Fig. A of Plate I., but on subsequent anneal with slow cooling, most of the Beta goes into solution and the banded appearance is lost, as shown in Fig. B of Plate I. It is clear, however, that Alpha regions which were previously occupied by Beta in banded form are regions of high zinc content, unless the treatment has brought about complete equalization of concentration throughout. Consequently, there will be a tendency towards a redevelopment of the banded structure when the alloy is heated to a temperature at which abundant separation of Beta can occur.

The present result signifies that this tendency is greater in the case of Alloy III than in the case of Alloy I. It indicates that the presence of arsenic in brass hinders the diffusional process to some extent. This cannot be regarded as a serious disadvantage of the arsenical alloy, as the low reduction of area developed by quenching at 700° , or above, is not seen in alloys cooled from this temperature, even through as little as 50°C. at almost any rate short of quenching.

It may be seen on examination of the curves representing elongation and reduction of area of Alloys I and III that the abrupt drop in the reduction of area of Alloy III, which we have attributed to a predominance of Beta in banded form, is not accompanied by a similar abrupt drop in elongation, but that the elongation curves of both mixtures follow the same general course. Thus it appears that, while close threads or bands of Beta parallel with the length of the test-strip operate to strengthen

the material against the shear stresses at the sides of the strip, thereby causing a break with diminished reduction of area, the elongation is influenced to a much lesser degree by this form of distribution of the Beta constituent.

The curves representing Alloy II, which is an arsenical alloy containing 61 per cent. of copper and therefore a much stronger but less ductile alloy than the others, are of the same type as those just described. Here, again, there is an abrupt drop in reduction of area (between 600° and 650° C.) which was found to correspond with a considerable increase in the number of parallel bands or stringers of Beta. All of the alloys were examined under the microscope, and photomicrographs representing the entire set, with the exception of alloys annealed and quenched at 500° C., are assembled in Plates III., IV., and V.

The results of the microscopic examination are in entire harmony with the testing results.

It is noticeable that at the lowest annealing temperature, viz. 450° C., the Alpha grain of the arsenical alloys (II and III) is at an earlier stage of recrystallization than the Alpha grain of the non-arsenical alloy; in the former case, the recrystallized grain is very fine and difficult to distinguish clearly at this magnification (see Figs. B and C of Plate III.), while in the latter case the grain is materially coarser (see Fig. A of the same plate). The pure brass doubtless begins to recrystallize at a lower temperature than the arsenical brass. This condition of affairs explains the intersection of the elongation curves of Alloys I and III just above 450° C.; i.e., after anneal at 450° C. the ductility of the arsenical metal is less than that of the non-arsenical metal owing to less complete recrystallization, while after anneal at higher temperatures, the characteristics of recrystallization are the same in both cases, and the ductility of the arsenical metal specifically exceeds that of the non-arsenical metal.

Bearing in mind the fact that all of the alloys in their original condition contained a small amount of Beta in the form of a network permeating the Alpha grains, as shown in Figs. A, B, and C of Plate II., it is noteworthy that after anneal at 550° C. the Alpha regions are free from intergranular Beta. This is shown in Figs. D, E, and F of Plate III., and it indicates that there is an absorption of Beta at this temperature, i.e. that the quantities

of Alpha and Beta originally present in the alloys can remain in equilibrium only at some temperature above 550°C . There has been little absorption at 450°C . because of the low velocity of the reaction at this temperature.

The photos taken after anneal at 600°C . show Alpha regions containing a small quantity of Beta in the case of Alloy I (Fig. A of Plate IV.), little or no Beta in the case of Alloy II (Fig. B), and a visible trace of Beta in the case of Alloy III (Fig. C).

Without dwelling at length on comparisons of this sort, we conclude from the photos of Plate IV. that Alloy I in its original form contained quantities of Alpha and Beta which would remain in equilibrium at about 600° , while Alloys II and III contained quantities which would remain in equilibrium at about 650°C . Since it was specified that all of the alloys constituting our present stock be treated simultaneously in mill operations, these tests indicate that absorption of Beta after a mill anneal proceeds more closely in accord with the equilibrium requirement in the case of a non-arsenical alloy.

The photos of Plate V. show greatly increased quantities of Beta on account of the high quenching temperatures employed. Here, Alloys I and III present quite a different appearance. Although the present magnification ($\times 76$) is not well adapted to the characterization of this difference, it is practically impossible to focus on a spot which does not show broad bands of Beta in Alloy III, while such bands are less frequently encountered in Alloy I. A better illustration of this feature may be seen in Figs. A and B of Plate VIII., representing the structure of Alloys I and III at a magnification of 22 after quenching at 700°C . These photos have already been cited in connection with a discussion of the different values of reduction of area shown by the two alloys in question.

Incidentally, the photos of the present collection show how greatly the quantity of Beta is influenced by slight variations in copper-content. For example, Alloys II and III differ by only one and one-half percentage units of copper, and yet the former contains about twice as much Beta as the latter after any of these treatments.*

* Calculations based upon the equilibrium diagram—assuming that the Alpha phase contains 65 per cent. of copper and the Beta phase 58.5 per cent., at 700°C .; and that the Alpha phase contains 64 per cent. of copper and the (apparent) Beta phase 52.5 per cent., at

It is perhaps appropriate at this time to state that microscopic examination of the quenched Beta phase under high power ($\times 1000$) showed a very finely lamellar internal structure. We attribute this to an incipient separation of Alpha, which would have taken a more readily visible form if the cooling had proceeded more slowly. As far as the present range of composition and quenching temperatures is concerned, this separation gives rise to the same appearance in all cases. It might be urged that the effect in question is really a manifestation of the presence of apparent Beta, but we do not believe that Beta can be quenched from a high temperature without separation of Alpha. Consequently, the duplex structure should be mainly due to separation of Alpha.

Other experiments in this laboratory have shown that if a pure brass containing 67 per cent. of copper is brought well into the Alpha + Beta field (880°C.) and quenched, the resulting Beta areas will possess a well-defined lamellar structure, readily visible at a magnification of 70 or 80. Accordingly, we have looked for intermediate structures, somewhat similar to the well-known stages in the transformation of Austenite, which might explain certain obscure features of the comparative tests after quenching at intermediate stages in the cooling of these alloys at different rates (to be described in a later section). No well-defined distinctions of this sort could, however, be made.

Before passing on to another subject, it may be said relative to the preparation of specimens for microscopic work that the arsenical alloys could invariably be distinguished by their peculiar behaviour in etching. Particularly when composed largely of Alpha, they acquire a surface dullness which interferes with the development of detail and diminishes the contrast. This is well illustrated by Fig. B of Plate I.

(d) Results obtained in the Second Series of Tests.

Table VIII. and the curves shown in Fig. 3 illustrate the effect of annealing strips of the three alloys at 700°C. for 15 minutes, cooling them at a rate of 5°C. per minute to temperatures

450°C. —show that the 61 per cent. alloy should contain 61.5 per cent. of Beta at 700°C. and the 62.5 per cent. alloy 38.5 per cent. of Beta; while the former alloy should contain 26 per cent. of Beta at 450°C. and the latter 13 per cent. of Beta.

TABLE VIII.—*Testing Data showing the Effect of Cooling at a Rate of 5° C. per Minute to Indicated Quenching Temperatures after 15 Minutes' Annedling at 700° C.*

No. of Test.	Grade * of Material.	Quenching Temperature, ° C.	Average Rate of Cooling, Degrees per Minute.	Tensile Strength, Lb. per Sq. In.	Reduction of Area per Cent.	Elongation per Cent. in 2 Inches.
81	I	650		51,800	56-10	65-00
82	I	650		51,900	56-10	64-00
		Average	5-3	51,850	56-10	64-50
83	II	650		58,800	48-80	55-50
84	II	650		58,800	48-80	55-00
		Average	5-1	58,800	48-80	55-25
85	III	650		52,800	54-80	68-00
86	III	650		52,600	54-85	67-00
		Average	5-4	52,700	54-83	67-50
87	I	600		49,800	58-70	69-00
88	I	600		49,800	59-00	69-00
		Average	5-7	49,800	58-85	69-00
89	II	600		57,000	49-60	59-00
90	II	600		57,000	49-90	59-00
		Average	5-2	57,000	49-75	59-00
91	III	600		50,600	58-00	73-50
92	III	600		50,800	58-00	73-50
		Average	5-8	50,700	58-00	73-50
93	I	550		49,300	59-60	72-00
94	I	550		49,300	60-10	72-00
		Average	5-3	49,300	59-85	72-00
95	II	550		55,500	52-40	62-00
96	II	550		55,400	52-35	60-00
		Average	5-1	55,450	52-38	61-00
97	III	550		49,800	58-10	75-00
98	III	550		49,700	58-10	75-00
		Average	5-2	49,750	58-10	75-00
99	I	500		48,400	59-90	72-00
100	I	500		48,300	59-85	73-00
		Average	4-7	48,350	59-88	72-50
101	II	500		54,600	55-40	65-00
102	II	500		54,800	55-50	65-00
		Average	5-1	54,700	55-45	65-00
103	III	500		48,900	59-30	75-00
104	III	500		49,000	59-20	75-00
		Average	5-1	48,950	59-25	75-00
105	I	450		47,900	60-90	74-00
106	I	450		47,900	60-00	71-00
		Average	5-1	47,900	60-45	72-50
107	II	450		53,800	56-40	66-00
108	II	450		53,700	56-40	66-00
		Average	5-5	53,750	56-40	66-00
109	III	450		48,700	59-30	75-00
110	III	450		48,600	59-20	75-00
		Average	5-4	48,650	59-25	75-00

* Composition of alloys:

No.	Per Cent. Copper.	Per Cent. Zinc.	Per Cent. Arsenic.	Per Cent. Iron.	Per Cent. Lead.
I	62-41	37-514	0-024	0-03	0-022
II	61-07	38-675	0-139	0-03	0-086
III	62-49	37-343	0-120	0-03	0-017

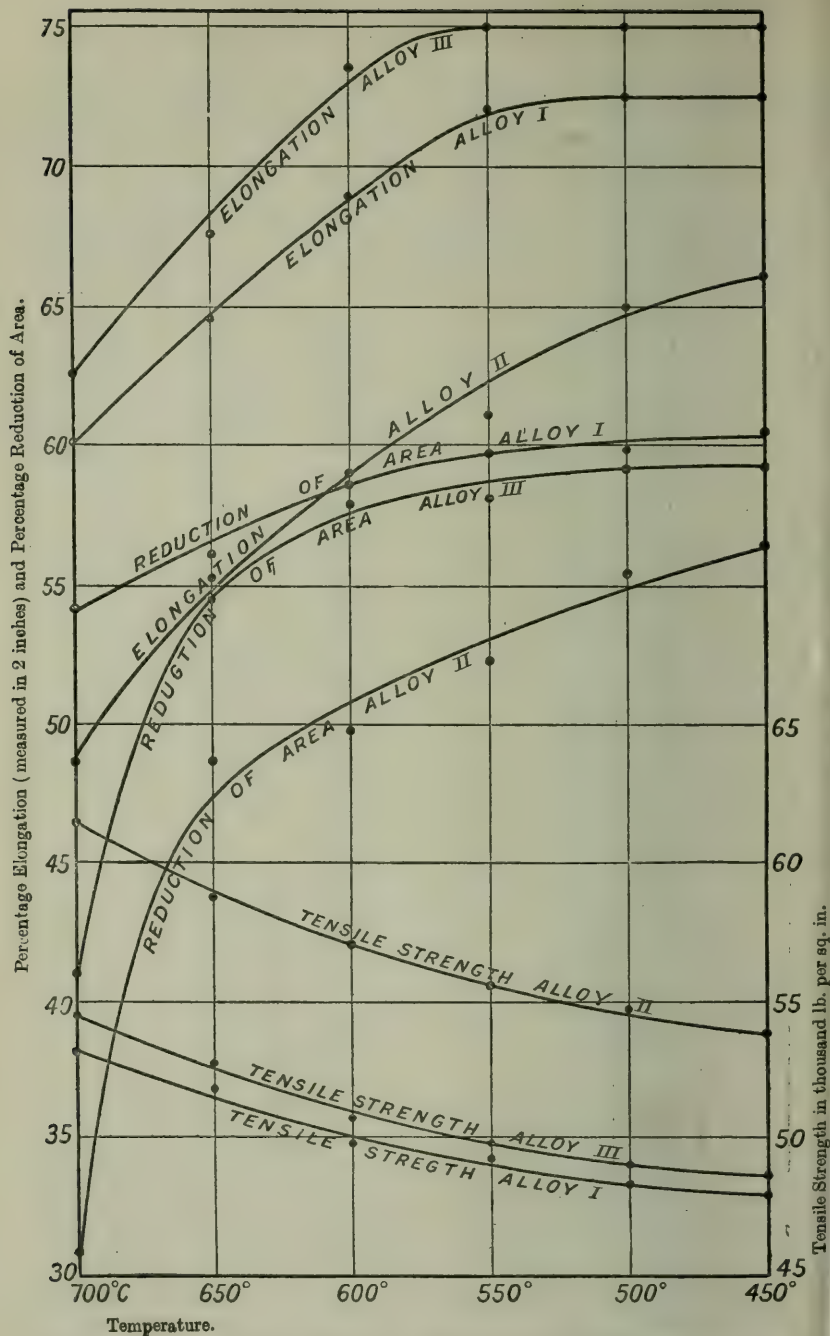


FIG. 3.—Effect of Cooling at a Rate of 5° per Minute to Indicated Quenching Temperatures after Fifteen Minutes' Annealing at 700° C.

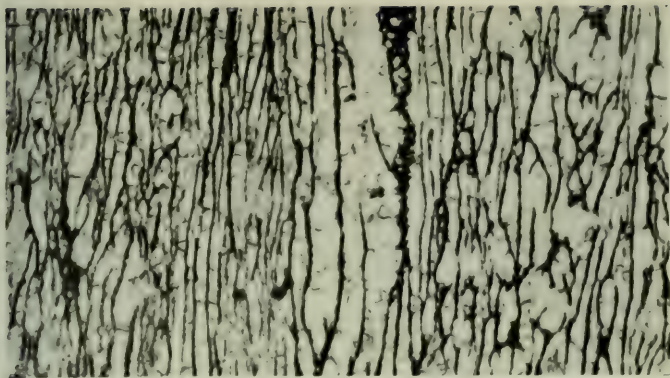


FIG. A.—Alloy III., Hot-Rolled.

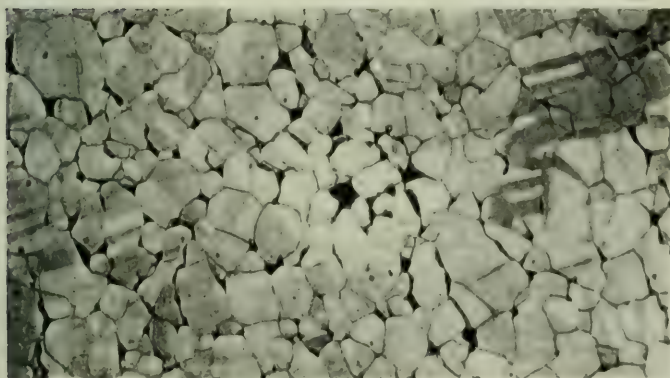


FIG. B.—Alloy III, as Received (annealed after hot-rolling).

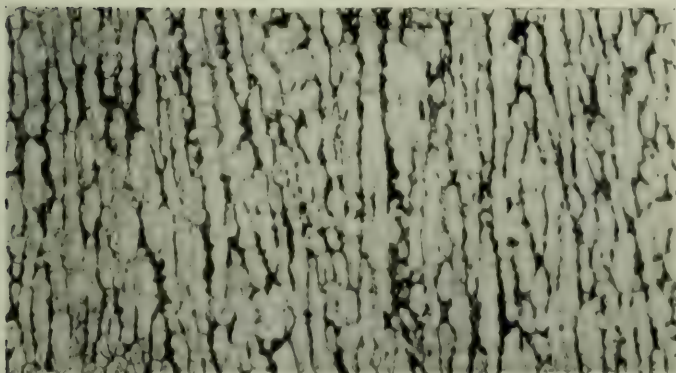


FIG. C.—Alloy II, as Received (annealed after hot-rolling).

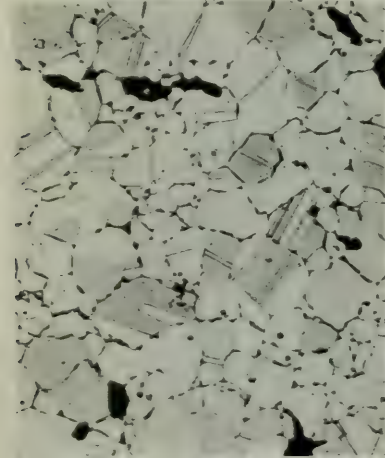


FIG. A.—Alloy I, 1st Anneal.

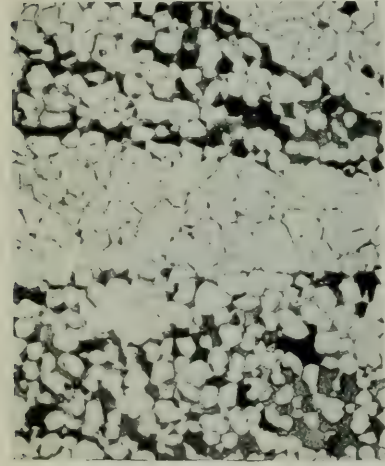


FIG. B.—Alloy II, 1st Anneal.

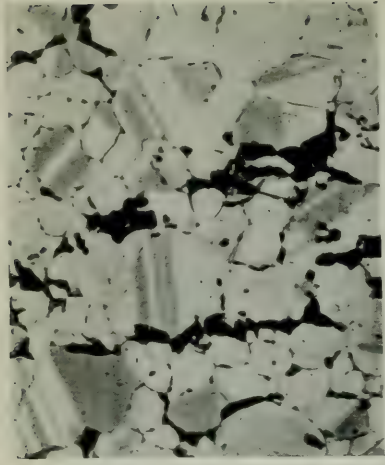


FIG. C.—Alloy III, 1st Anneal.

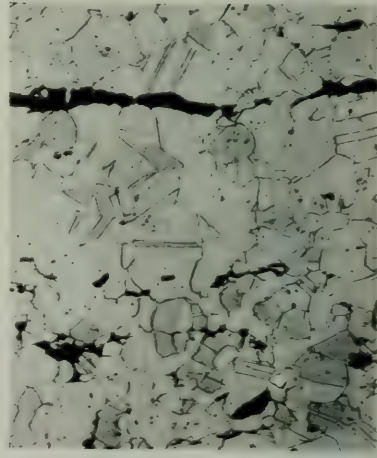


FIG. D.—Alloy I, 2nd Anneal.

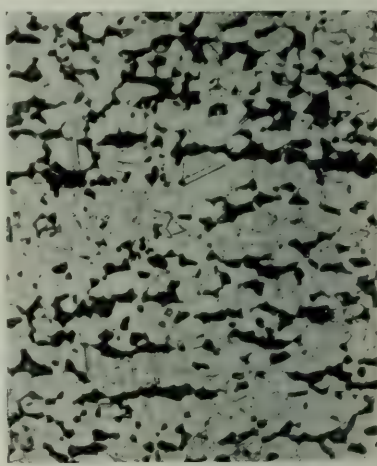


FIG. E.—Alloy II, 2nd Anneal.

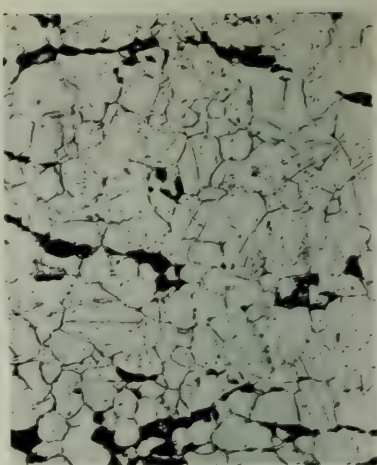


FIG. F.—Alloy III, 2nd Anneal.

Rolled strips annealed one hour at 650° C. and slowly cooled preparatory to finishing passes. Alloys I and III contain 62.5 per cent. of copper; Alloy II, 61 per cent. Specimens etched with ammonia and hydrogen peroxide followed by ferric chloride. Magnification, $\times 76$.

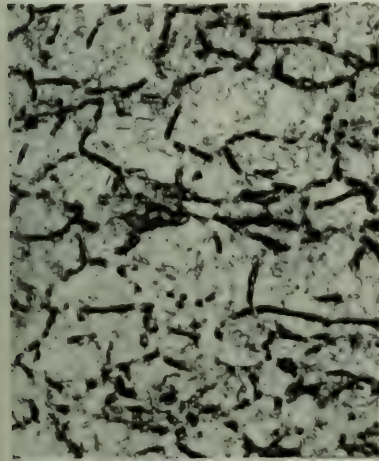


FIG. A.—Alloy I, 450°C.

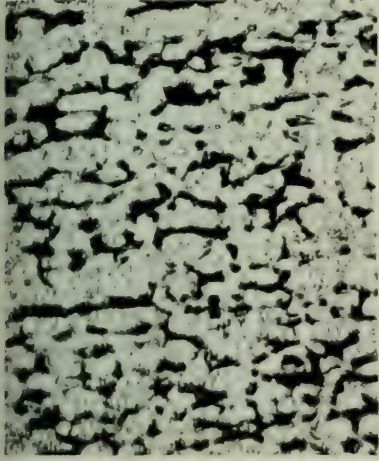


FIG. B.—Alloy II, 450°C.

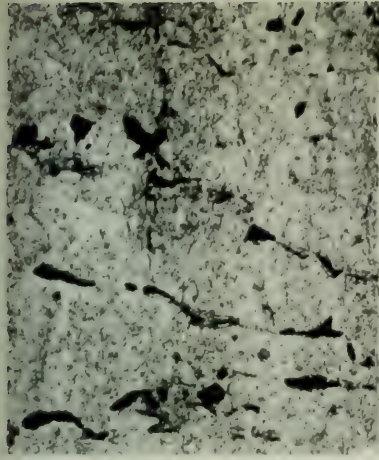


FIG. C.—Alloy III, 450°C.

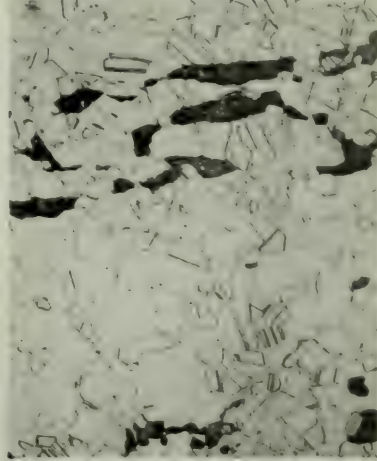


FIG. D.—Alloy I, 550°C.

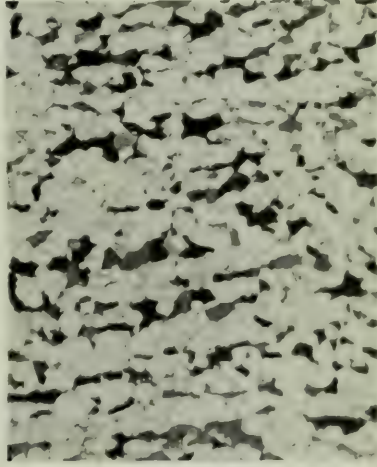


FIG. E.—Alloy II, 550°C.

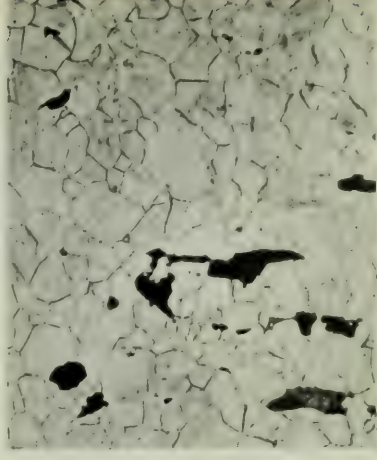


FIG. F.—Alloy III, 550°C.

Strips annealed 15 minutes at indicated temperatures and then quenched in water. Alloys I and III contain 62.5 per cent. of copper; Alloy II, 61 per cent. Specimens etched with ammonia and hydrogen peroxide followed by ferric chloride. Magnification, $\times 76$.

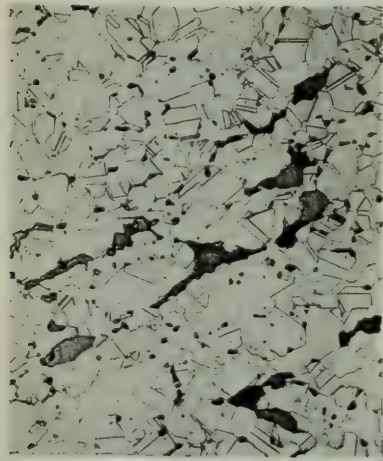


FIG. A.—Alloy I, 600 C.

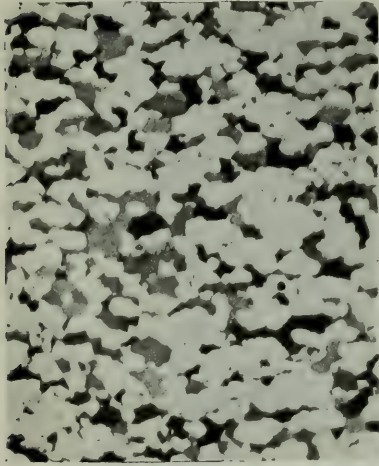


FIG. 13.—Alloy II., 600° C.

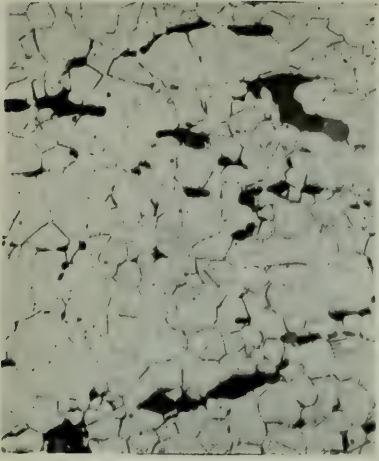


FIG. C.—Alloy III., 600° C.

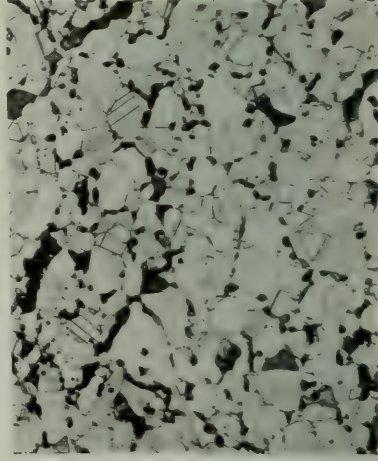


FIG. D.—Alloy I., 650° C.

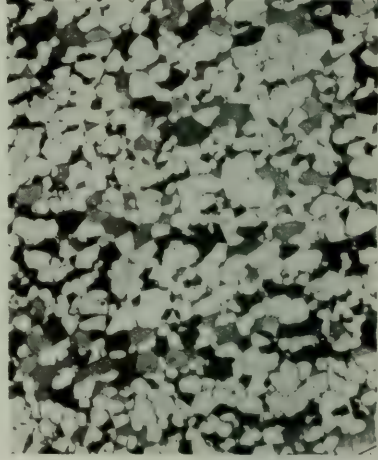


FIG. E.—Alloy II., 650° C.

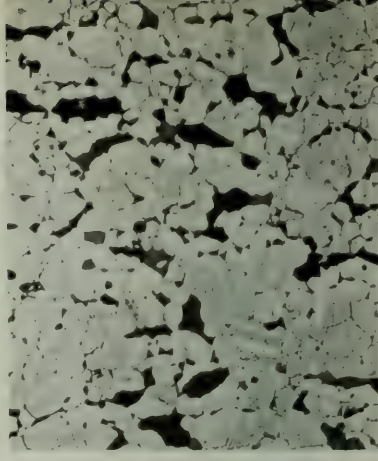


FIG. F.—Alloy III., 650° C.

Strips annealed 15 minutes at indicated temperatures and then quenched in water. Alloys I and III, contain 62.5 per cent. of copper; Alloy II, 61 per cent. Specimens etched with aqueous cuprous iodine solution followed by ferric chloride. Magnification $\times 75$.

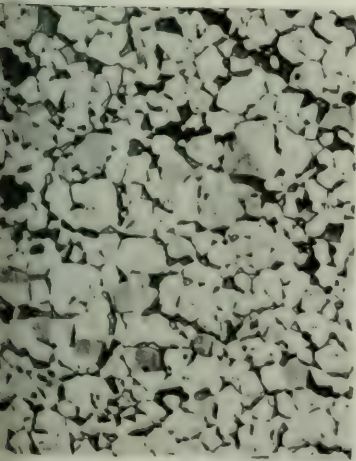


FIG. A.—Alloy I, 700° C.

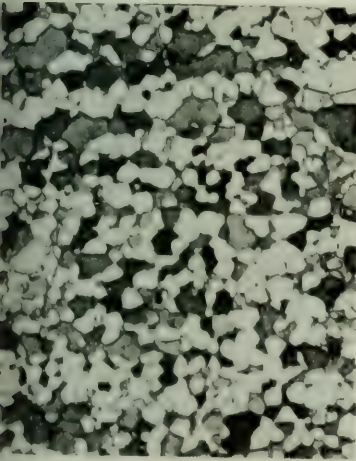


FIG. B.—Alloy II, 700° C.

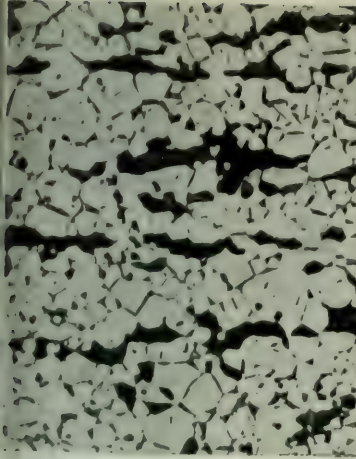


FIG. C.—Alloy III, 700° C.

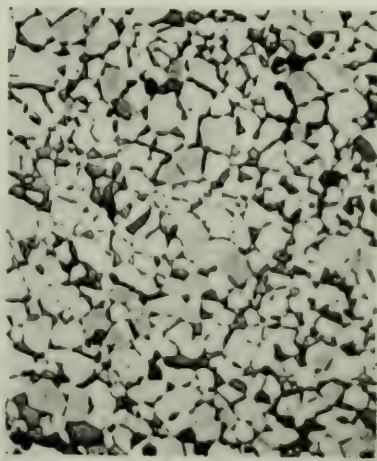


FIG. D.—Alloy I, 750° C.

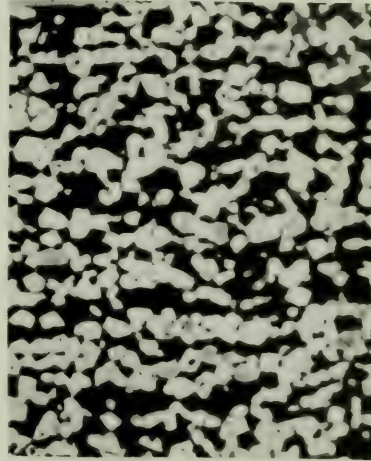


FIG. E.—Alloy II, 750° C.

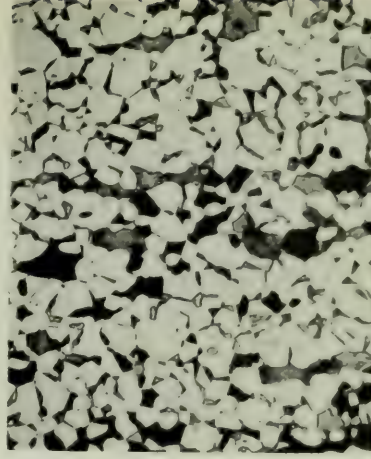


FIG. F.—Alloy III, 750° C.

Strips annealed 15 minutes at indicated temperatures and then quenched in water. Alloys I and III contain 62.5 per cent. of copper; Alloy II, 61 per cent. Specimens etched with ammonia and hydrogen peroxide followed by ferric chloride. Magnification, $\times 76$.

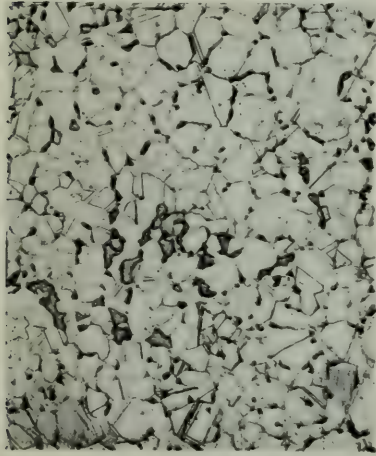


FIG. A.—Alloy I, 5° per m., 450° C.

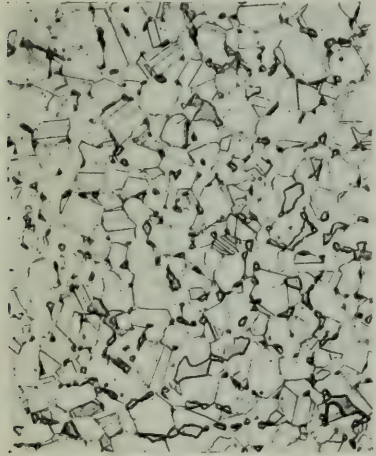


FIG. B.—Alloy I, 5° per m., 550° C.

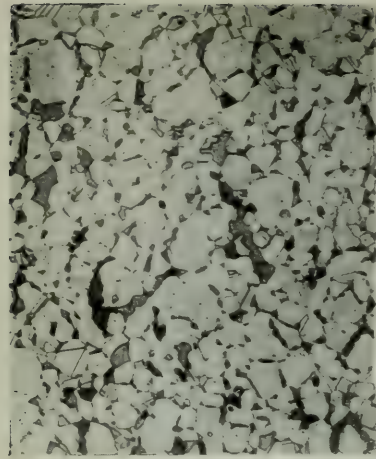


FIG. C.—Alloy I, 5° per m., 650° C.

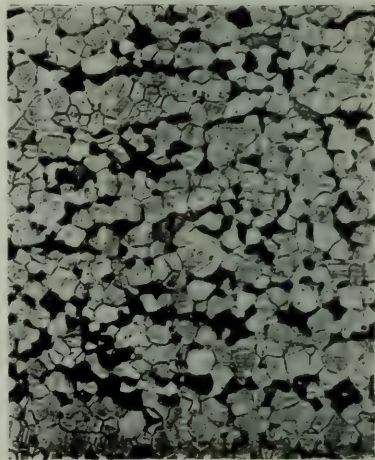


FIG. D.—Alloy II, 5° per m., 450° C.

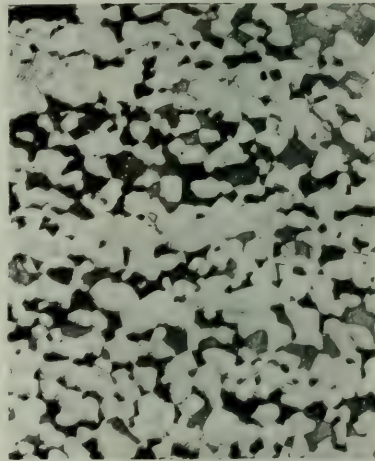


FIG. E.—Alloy II, 5° per m., 550° C.

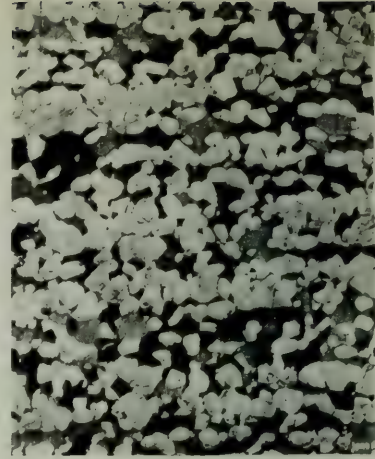


FIG. F.—Alloy II, 5° per m., 650° C.

Strips annealed 15 minutes at 700° C. and cooled at indicated rates to quenching temperatures. Alloy I contains 62.5 per cent. of copper; Alloy II, 61 per cent. Specimens etched with ammonia and hydrogen peroxide followed by ferric chloride. Magnification, $\times 76$.

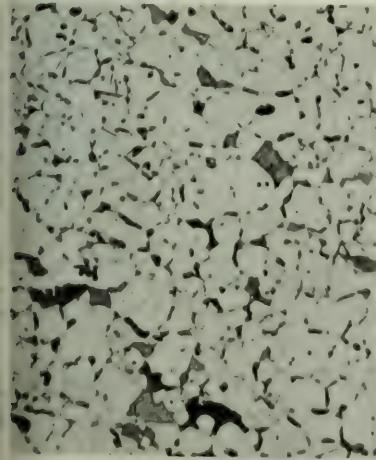


FIG. A.—Alloy I, 20 per m., 450° C.

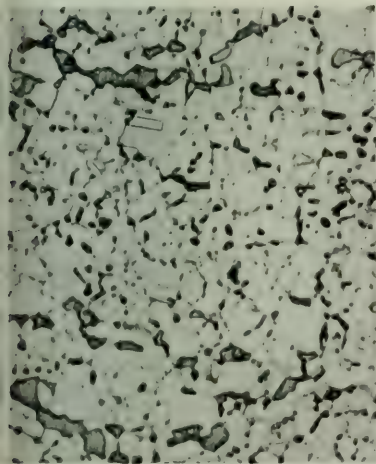


FIG. B.—Alloy I, 20 per m., 550° C.

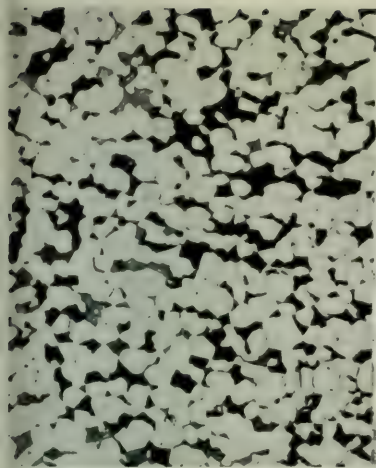


FIG. C.—Alloy II, 20 per m., 450° C.

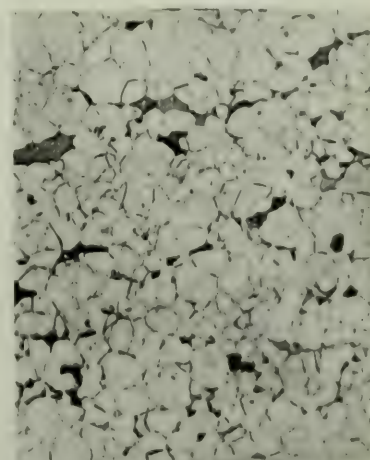


FIG. D.—Alloy III, 20 per m., 450° C.

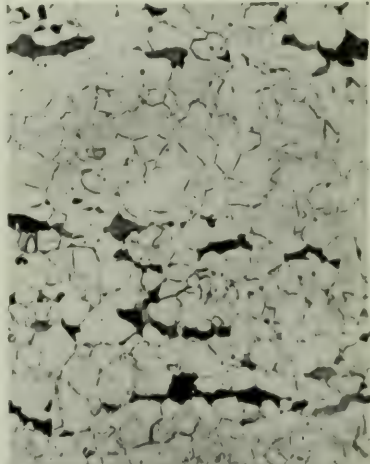


FIG. E.—Alloy III, 50 per m., 450° C.

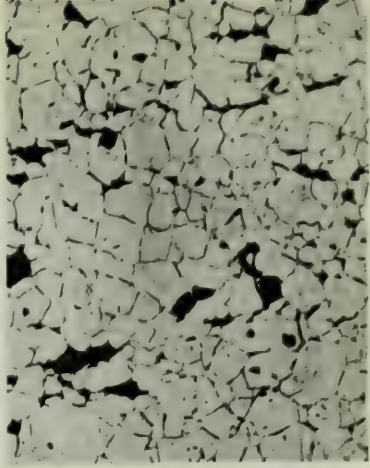


FIG. F.—Alloy III, 100 per m., 450° C.

Strips annealed 15 minutes at 700° C. and cooled at indicated rates to indicated temperatures. Alloys I, and III, contain 62.5 per cent of copper; Alloy II, 61 per cent. Specimens etched with ammonia and hydrogen peroxide followed by ferric chloride. Magnification, $\times 76$.



FIG. A.—Alloy I, Quenched at 700° C.

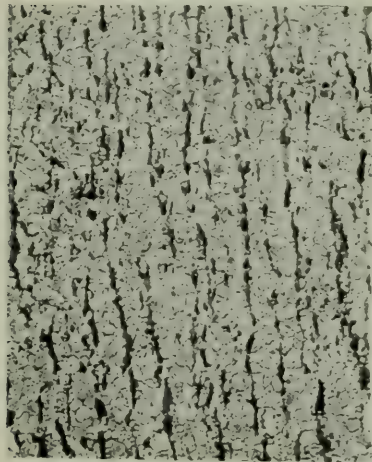


FIG. B.—Alloy III, Quenched at 700° C.

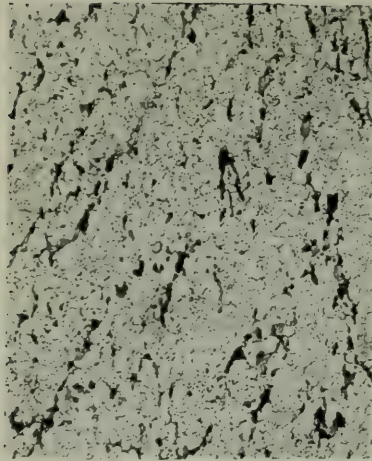


FIG. C.—Alloy III, 20 per m., 650° C.

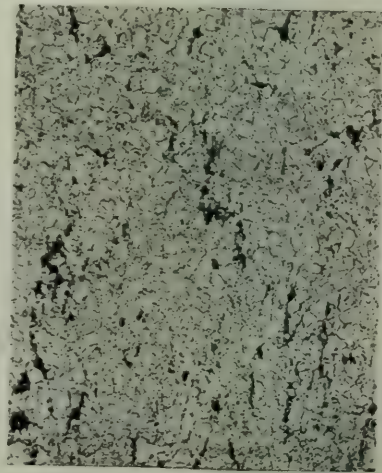


FIG. D.—Alloy I, 50 per m., 450° C.

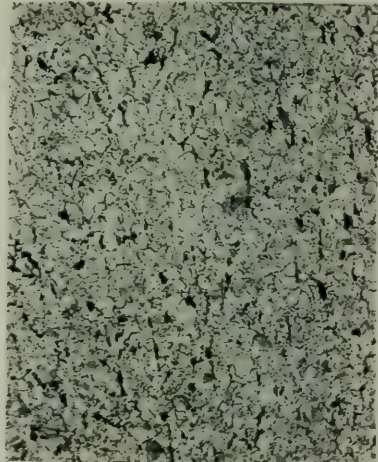


FIG. E.—Alloy I, 50 per m., 550° C.

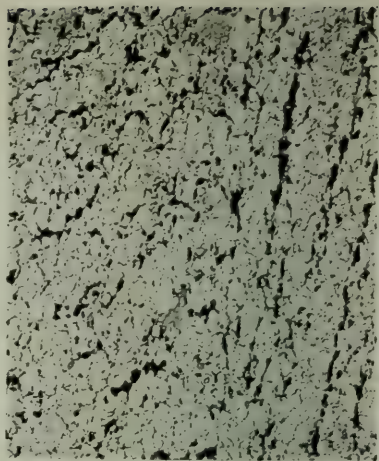


FIG. F.—Alloy III, 50 per m., 600° C.

Strips annealed 15 minutes at 700° C. and cooled at indicated rates to indicated quenching temperatures. Alloys contain 62.5 per cent. of copper. Specimens

varying from 650° to 450° C., and thereupon quenching them in water. This and the other three groups of tests of the present series thus deal with the loss of strength and the recovery of ductility encountered at different stages of a specified process of cooling.

Between 700° and 600° C. the elongation of the 62.5 per cent. alloys (I and III) rises quite rapidly and thereafter at a rapidly decreasing rate, finally reaching a nearly constant value in the range 550° to 450° C. The reduction of area behaves similarly, but the change is not as pronounced in the case of the non-arsenical alloy, and the values between 550° and 450° C. are less uniform. The tensile strength decreases gradually at a slightly diminishing rate throughout the entire cooling range.

The values of elongation and tensile strength are higher throughout the entire range in the case of the arsenical alloy, while the values of reduction of area are higher in the case of the non-arsenical alloy.

The abrupt change of properties between 700° and 600° C., followed by a more gradual change, and finally by little or no change between 550° and 450° C., indicates that the absorption of Beta is rapid in the early stages of cooling, then more gradual, and virtually at a standstill in the last stages.

This was verified by structural observations on the entire set of alloys and three illustrative photomicrographs, taken from Alloy I, are given in Figs. A, B, and C of Plate VI. Fig. C, representing the structure after cooling to 650° C., should be compared with Fig. A of Plate V., representing the initial quenched structure; i.e., the structure before cooling to 650° C. at the present rate. It is quite clear that a notable decrease in the quantity of Beta has been effected by cooling through this short temperature interval of 50° C. Figs. A and B of Plate VI. represent the structure after cooling to 450° and to 550° C., respectively. There is very little difference between these two structures, and we conclude that the amount of Beta which remains after cooling at the present rate of 5° per minute to 550° C. is not sensibly diminished by further cooling.

In discussing the results obtained in the *First Series of Tests* we presented micrographic evidence to explain the much lower reduction of area shown by Alloy III than by Alloy I after

quenching at 700°C . Evidence of the same character is now brought forward to explain the remarkable increase in reduction of area which occurs when the alloy is quenched after cooling to 650°C ., instead of directly at 700°C . The comparison may be seen in Figs. B and C of Plate VIII. In Fig. B, representing Alloy III quenched at 700°C ., numerous parallel bands of Beta are seen, while in Fig. C, representing Alloy III quenched after cooling from 700° to 650°C ., the bands have been broken up by partial absorption of Beta.

In general, it may be emphasized the two mixtures described thus far give curves of the same type, and that these curves certainly indicate active absorption of Beta down to temperatures in the neighbourhood of 550°C ., after which the absorption of Beta becomes unimportant. The quantity of Beta left naturally corresponds to that which is in equilibrium at some temperature higher than the point on a given curve where the rate of change of elongation, or other indicated property, becomes zero, i.e., the absorption cannot meet the equilibrium requirement except in the earliest part of the range. The simplest way to determine this equilibrium temperature is to compare the quantity of Beta left in the given alloy with the different quantities developed by annealing and quenching at a succession of temperatures, i.e., with the structures developed in the *First Series of Tests*. Thus, the temperature sought will be the one at which the same quantity of Beta has developed as was observed in the alloy under consideration. The two structures in question are shown in Fig. A of Plate VI. and Fig. A of Plate IV. The first of these represents Alloy I quenched after cooling from 700° to 450°C ., and the other represents the same alloy quenched after annealing at 600°C . They give the closest comparison possible on the basis of the 50° stages adopted in these heat treatments, and we conclude that Alloy I after cooling at a rate of 5° per minute to 450°C . contains quantities of Alpha and Beta which correspond to equilibrium at some 600°C . When we compare the mechanical properties of these alloys, we find that their values of elongation differ by only two and a quarter percentage units and their values of tensile strength by 1100 lb. per square inch, viz., they are closely alike. Even with structures showing exactly the same quantities of Beta in a comparison of this sort, we would hardly

look for identical properties, since the Alpha grain of the alloy annealed and quenched at a certain temperature has developed by recrystallization at or below that temperature, while the Alpha grain of the alloy initially heated to a higher temperature and then cooled to a lower temperature has developed under totally different conditions; mainly as a result of the breakdown of Beta through a high temperature range. As a matter of fact, these comparisons show higher ductility and lower strength in the case of alloys cooled after a high temperature of anneal.

From a practical standpoint, the curves thus far described indicate that in order to obtain maximum ductility in cooling alloys of the present type at a rate of 5° C. per minute, such cooling should be continued down to some 550° C., after which the alloys may be cooled in a stream of water without ill effect.*

The Copper Range alloy containing 61 per cent. of copper (Alloy II) gives curves of a somewhat different type. Here, the elongation and reduction of area continue to rise prominently down to the very lowest temperature of quenching. (See Fig. 3.)

From the photomicrographs of the present set, it may be seen that the quantities of Beta present in Alloy II are much greater than those present in Alloy I (or Alloy III) after the same treatment. For example, compare Figs. D, E, and F of Plate VI. with Figs. A, B, and C, respectively of the same plate.

Furthermore, it is apparent that in the case of Alloy II, continuation of the cooling process at the present rate of 5° per minute beyond 550° C. (to 450°) results in a visible decrease in the quantity of Beta. This may be seen by comparing Figs. E and D of Plate VI.

The reason for the above-mentioned persistent change of properties down to the very lowest quenching temperature is thus ascribed to a plainly visible change in the quantity of Beta. In the case of Alloys I and III, the corresponding change of properties was inappreciable and no change in the quantity of Beta could be detected with certainty.

It should be remarked, however, that a relative change of

* Gradual changes of reduction of area and tensile strength in the very lowest part of the cooling range seem to indicate that slight additional ductility or softening may be secured by continuing this form of cooling down to 450° C., or even a lower temperature. The exact reasons for the cross-relationships between elongation, reduction of area, and tensile strength in the region of low temperature have not been ascertained.

the same intensity would be less perceptible in the case of Alloy I than in the case of Alloy II, which contains approximately twice as much Beta. Thus, according to the equilibrium diagram, Alloy I contains 38.5 per cent. of Beta at 700° C. and Alloy II 61.5 per cent.; while the former alloy contains 13 per cent. of Beta at 450° and the latter alloy 26 per cent. On cooling there will be a pronounced lag in the absorption of Beta, so that much less than the above requirement of 64 per cent. absorption in the case of Alloy I and .58 per cent. absorption in the case of Alloy II will be realized. If, now, we assume that 75 per cent. of the theoretical absorption actually occurs and one-quarter of this between the temperatures 550° to 450° C., Alloy I will contain 24.6 per cent. of Beta and Alloy II 41.5 per cent. of Beta at 550° C., while Alloy I will contain 20.0 per cent. of Beta and Alloy II 34.8 per cent. of Beta at 450° C.

To take the bearing of this on a specific property; if the elongation, for example, is proportional to the quantity of Alpha, there would be an increase in elongation of about 6 per cent. in the case of Alloy I and of about 11 per cent. in the case of Alloy II, due to continuation of cooling from 550° to 450° C. The actual increase is less than 1 per cent. in the case of Alloy I and more than 8 per cent. in the case of Alloy II.

The above are fair assumptions on a basis that the absorption of Beta proceeds similarly in both alloys, but the results are not in accord with the actual results of tests, as the final comparison shows. It is noticeable that the elongation of Alloy II after cooling at the present rate to the lowest quenching temperature (66 per cent.) is higher than the maximum elongation obtained in the *First Series of Tests* (62.25 per cent.), while the elongation of Alloy I after the same treatment (72.5 per cent.) falls short of the corresponding maximum obtained in the *First Series of Tests* (74.25 per cent.). This is distinct evidence that the absorption of Beta follows the equilibrium requirement more closely in Alloy II than in Alloy I. The situation obviously has to do with a variable facility of adjustment between the Alpha and Beta phases, perhaps determined by the relative areas of inner surfaces exposed by the two constituents. When the quantities of Alpha and Beta are approximately the same, a different impulse towards adjustment in the direction of equilibrium may well occur than

when the quantity of Alpha is small in comparison with the quantity of Beta; assuming the same heat treatment in both cases.

Table IX. contains the testing data obtained after quenching strips of the three alloys at different temperatures in the course of cooling at a rate of 20° C. per minute from an initial annealing temperature of 700° C. The tabulated averages are plotted in Fig. 4.

Here again, in the case of Alloys I and III there appears to be a halting point in the absorption of Beta at 550° C., since the values of elongation, reduction of area, and tensile strength remain sensibly constant below this temperature. It should be noted, however, that the end values represent a further departure from equilibrium conditions than in the former case (cooling at a rate of 50° C. per minute).* In other words, the absorption of Beta does not proceed as far and does not result in as ductile metal in the present case.

As before, the elongation and tensile strength values given by the arsenical alloy are superior to respective values given by the non-arsenical alloy, while the arsenical alloy shows lower values of reduction of area. There is the same recovery of ductility, in terms of reduction of area, between 700° and 650° C. as was observed in the earlier case, and the previous explanation is equally acceptable.

From a practical standpoint, these curves indicate that the present rate of cooling, 20° C. per minute, is too rapid to develop the high ductility which would be desirable in the event of severe cold-working requirements. On no account should quenching take place at temperatures above 550° C. after treatment of this character.

The 61 per cent. Copper Range alloy (Alloy II) again shows a progressive increase of elongation throughout the entire temperature range of cooling. Reasons for this behaviour were advanced in a discussion of the earlier case.

A few photomicrographs illustrating the structures of the three alloys after cooling at the present rate are given in Plate VII. Figs. A and B represent Alloy I cooled to 450° and 550° C.

* For example, the maximum value of elongation of Alloy I is some 3.5 percentage units less after cooling at the 20° rate than after cooling at the 5° rate.

TABLE IX.—*Testing Data Showing the Effect of Cooling at a Rate of 20° C. per Minute to Indicated Quenching Temperature after 15 Minutes' Annealing at 700° C.*

No. of Test.	Grade * of Material.	Quenching Temperature. ° C.	Average Rate of Cooling, Degrees per Minute.	Tensile Strength, Lb. per Sq. In.	Reduction of Area per Cent.	Elongation per Cent. in 2 Inches.
111	I	650		53,300	55.40	65.00
112	I	650		53,300	55.55	65.00
		Average	20	53,300	55.58	65.00
113	II	650		60,000	51.80	53.00
114	II	650		60,300	51.50	53.00
		Average	20	60,150	51.65	53.00
115	III	650		53,300	55.00	66.00
116	III	650		53,300	55.00	66.00
		Average	20	53,300	55.00	66.00
117	I	600		51,300	56.10	65.50
118	I	600		51,400	56.10	66.00
		Average	20	51,350	56.10	65.75
119	II	600		57,100	53.60	53.50
120	II	600		57,200	53.80	54.50
121	II	600		58,000	53.80	59.00
122	II	600		58,100	53.90	57.00
		Average	19.8	57,600	53.78	56.00
123	III	600		51,900	57.00	69.00
124	III	600		51,900	56.90	69.00
		Average	20	51,900	56.95	69.00
125	I	550		49,900	58.30	69.00
126	I	550		49,800	58.30	69.00
		Average	19.8	49,850	58.30	69.00
127	II	550		56,800	54.20	61.00
128	II	550		56,500	54.10	61.00
		Average	19.8	56,650	54.15	61.00
129	III	550		51,200	57.50	70.00
130	III	550		51,200	57.50	69.00
		Average	20	51,200	57.50	69.50
131	I	500		49,900	58.00	69.00
132	I	500		50,000	57.90	68.50
		Average	20.1	49,950	57.95	68.75
133	II	500		56,000	53.80	62.50
134	II	500		56,100	53.80	60.50
		Average	20.1	56,050	53.80	61.50
135	III	500		50,900	57.30	70.00
136	III	500		51,000	57.80	69.00
		Average	20.3	50,950	57.55	69.50
137	I	450		49,900	57.80	69.00
138	I	450		50,000	57.70	69.00
		Average	20.3	49,950	57.75	69.00
139	II	450		55,800	53.70	63.00
140	II	450		56,000	53.40	63.00
		Average	20	55,900	53.55	63.00
141	III	450		50,800	57.50	70.00
142	III	450		50,900	57.50	70.50
		Average	19.8	50,850	57.50	70.25

* Composition of Alloys:

No.	Per Cent. Copper.	Per Cent. Zinc (difference).	Per Cent. Arsenic.	Per Cent. Iron.	Per Cent. Lead.
I	62.41	37.514	0.024	0.03	0.022
II	61.07	38.675	0.139	0.03	0.086
III	62.49	37.343	0.120	0.03	0.017

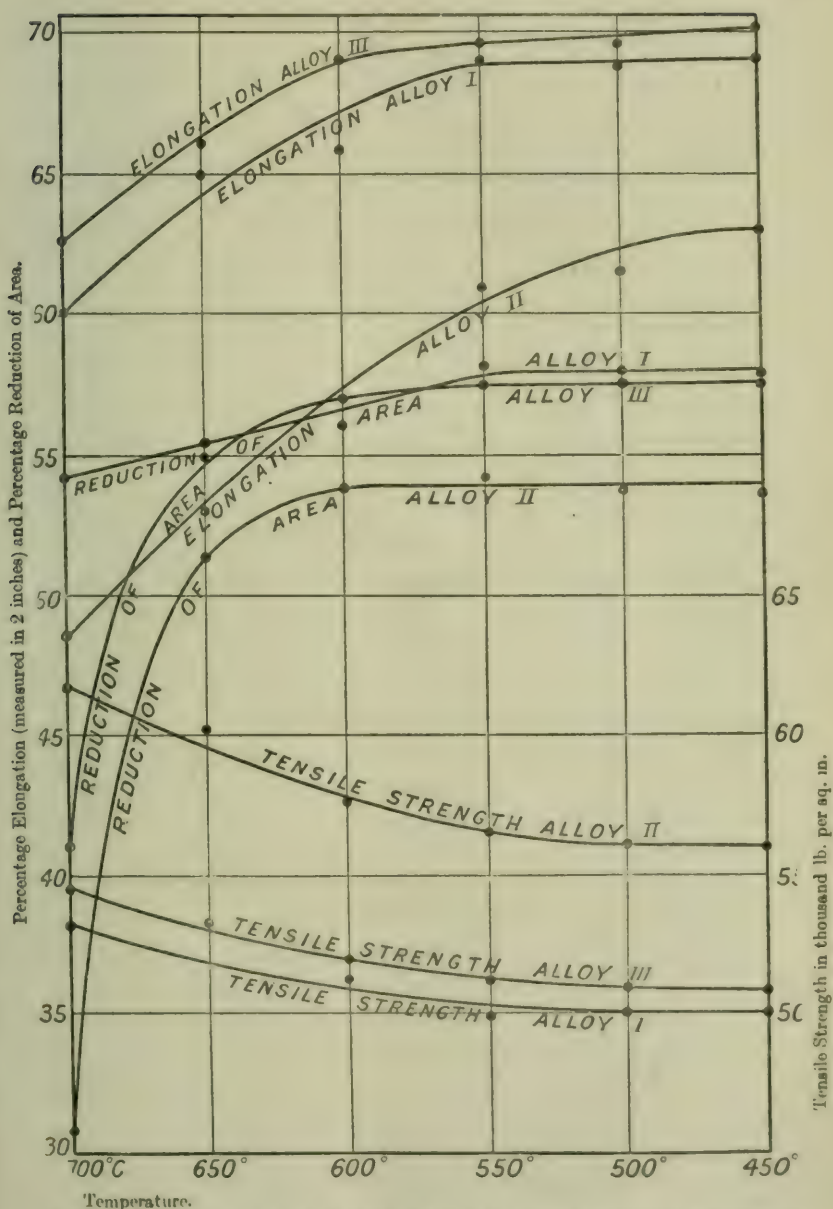


FIG. 4.—Effect of Cooling at a Rate of 20° per Minute to Indicated Quenching Temperatures after Fifteen Minutes' Annealing at 700° C.

respectively. Approximately the same quantity of Beta is shown in both cases and a comparison with the photos from alloys quenched directly after annealing at different temperatures indicates that the quantity in question is similar to that which remains in equilibrium with Alpha at 650° C. (Fig. D of Plate IV.).

Fig. C of Plate VII. represents Alloy II cooled to 450° C. Here, the quantity of Beta compares roughly with that obtained by direct quenching after anneal at 550° or 600° C. (Fig. E of Plate III. or Fig. B of Plate IV.), thus indicating that the absorption of Beta is more effective in this alloy than in Alloy I.

Fig. D of Plate VII. represents Alloy III cooled to 450° C. This alloy contains considerably less Beta in the form of a network than Alloy I, treated similarly (Fig. A of the same plate), but visual examination at low magnification shows that there is a more frequent occurrence of Beta in patches in the case of Alloy III. This is one of the characteristics of the arsenical alloys, viz., Beta tends to separate locally in patches, or after enough accumulates, in bands, as previously pointed out when seeking to explain notable changes in reduction of area. By comparing Figs. A and C of Plate VII., representing the ultimate structures obtained after cooling at the present rate of 20° C. per minute, with Figs. A and D, respectively, of Plate VI., representing similar structures obtained after cooling at the previous rate of 5° C. per minute, it will be seen that larger quantities of Beta remain after the present form of treatment. The higher strengths and lower ductilities of the present set of strips are to be explained on this basis.

Table X. and the corresponding curves of Fig. 5 represent the effect of cooling Alloys I, II, and III at a rate of 50° C. per minute to the various quenching temperatures after a 15-minute anneal at 700° C. It is noticeable in the present set of tests that all the curves of elongation and reduction of area continue to rise throughout the entire temperature range of cooling. Thus, this very rapid cooling of Alloys I and III has produced conditions similar to those observed at all rates of cooling in the case of Alloy II. In other words, a lag in the absorption of Beta by Alpha and in the separation of Alpha from Beta has caused Alloys I and III to reach the lower temperature range with a sufficient excess of Beta to bring about more active changes at these

TABLE X.—Testing Data Showing the Effect of Cooling at a Rate of 50° C. per Minute to Indicated Quenching Temperature, after 15 Minutes' Annealing at 700° C.

No. of Test.	Grade * of Material.	Quenching Temperature. C.	Average Rate of Cooling, Degrees per Minute.	Tensile Strength, Lb. per Sq. In.	Reduction of Area per Cent.	Elongation per Cent. in 2 Inches.
143	I	650		53,300	55.90	64.00
144	I	650		53,400	55.90	64.00
		Average	49	53,350	55.90	64.00
145	II	650		60,000	48.60	51.00
146	II	650		60,100	48.80	51.00
		Average	51	60,050	48.70	51.00
147	III	650		54,000	55.90	65.00
148	III	650		54,000	55.40	65.00
		Average	50	54,000	55.65	65.00
149	I	600		53,000	55.80	65.00
150	I	600		52,800	56.50	65.00
		Average	50	52,900	56.15	65.00
151	II	600		59,100	51.40	55.00
152	II	600		59,100	51.20	55.50
		Average	50	59,100	51.30	55.25
153	III	600		53,300	56.80	67.00
154	III	600		53,200	57.10	67.00
		Average	50	53,250	56.95	67.00
155	I	550		51,400	57.60	66.00
156	I	550		51,700	57.30	66.00
		Average	50	51,550	57.45	66.00
157	II	550		58,100	51.50	59.00
158	II	550		58,100	51.80	59.00
		Average	50	58,100	51.65	59.00
159	III	550		52,500	56.90	67.00
160	III	550		52,400	57.00	67.00
		Average	50	52,450	56.95	67.00
161	I	500		51,200	57.90	67.50
162	I	500		51,100	58.00	67.00
		Average	50	51,150	57.95	67.25
163	II	500		57,000	52.20	62.00
164	II	500		57,000	52.40	62.00
		Average	50	57,000	52.30	62.00
165	III	500		51,800	57.50	69.00
166	III	500		51,900	58.00	69.00
		Average	50	51,850	57.75	69.00
167	I	450		51,000	58.80	69.00
168	I	450		50,700	58.50	69.00
		Average	50	50,850	58.65	69.00
169	II	450		56,900	52.40	62.00
170	II	450		56,700	52.40	64.00
		Average	50	56,800	52.40	63.00
171	III	450		51,700	58.50	70.00
172	III	450		51,600	58.40	70.00
		Average	50	51,650	58.45	70.00

* Composition of Alloys:

No.	Per Cent. Copper.	Per Cent. Zinc (difference).	Per Cent. Arsenic.	Per Cent. Iron.	Per Cent. Lead.
I	62.41	37.514	0.024	0.03	0.022
II	61.07	38.675	0.139	0.03	0.086
III	62.49	38.343	0.120	0.03	0.017

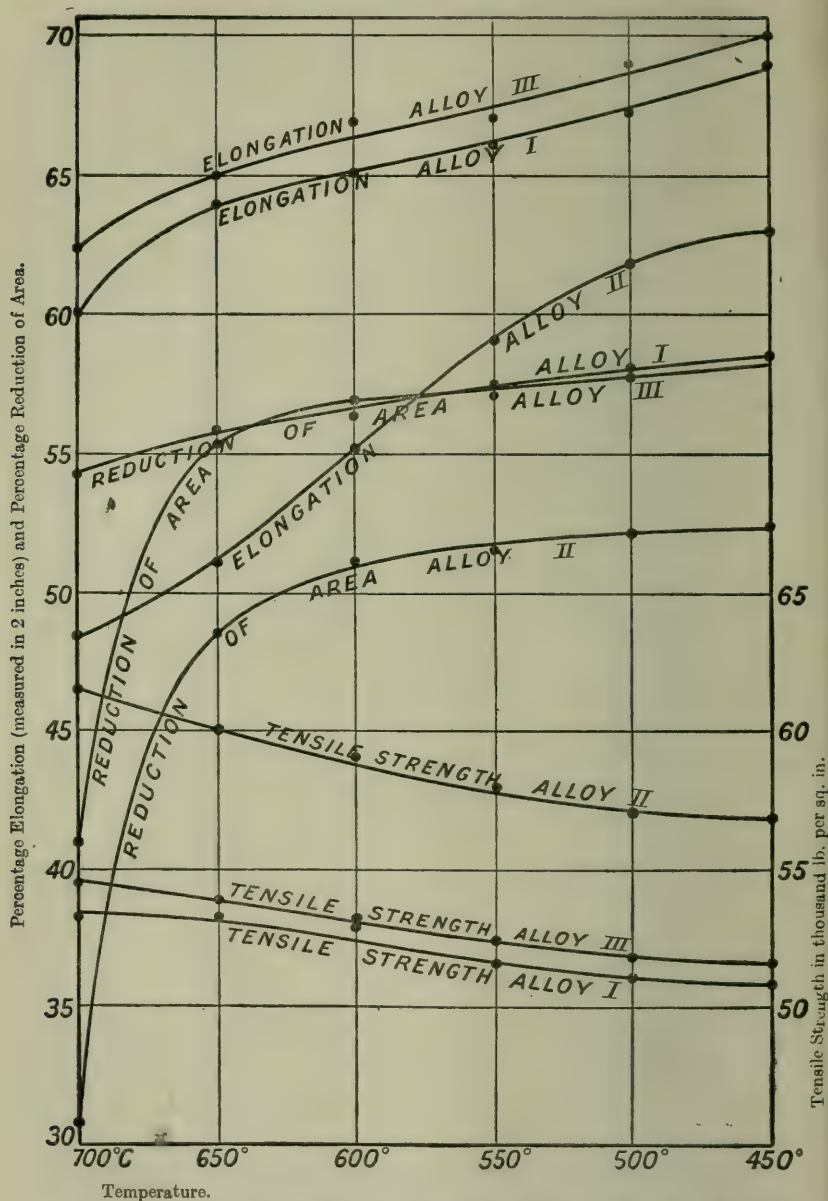


FIG. 5.—Effect of Cooling at a Rate of 50° per Minute to Indicated Quenching Temperatures after Fifteen Minutes' Annealing at 700° C.

temperatures.* It seems probable that curves of the first type, e.g., the elongation curve of Alloy I in Fig. 3, always change to curves of the second type, e.g., the elongation curve of Alloy I in Fig. 5, when the rate of cooling becomes sufficiently rapid; while metal sufficiently low in copper gives curves of the second type throughout a very wide variation in the rate of cooling. These conditions have to do with the relative quantities of Alpha and Beta encountered, along with certain features of distribution, as already indicated in an earlier discussion.

We made a particular effort to determine whether a difference could be detected in the quantities of Beta remaining in Alloy I after cooling to 550° C., in the one case, and to 450° C., in the other. These treatments correspond to a difference in elongation of about three percentage units. After careful examination at a variety of magnifications, we feel certain that a visible reduction in the quantity of Beta takes place when cooling is continued from 550° to 450° C. Carefully selected photomicrographs representing this difference are shown in Figs. D and E of Plate VIII. Since it is necessary to use a low magnification for these comparisons, in order that considerable surface may be exposed, and since the detail is very fine under such conditions, we are not at all certain that the distinction will be clear in the half-tones.

It is interesting to note that cooling at this rapid rate of 50° per minute between 700° and 650° C. brings about practically the same increase in reduction of area in Alloy III as was effected by cooling at the rate of 5°, or 20° C. per minute. Photomicrographs at low magnification representing this alloy after quenching at 700° C., after cooling to 650° C. at a rate of 20° C. per minute and then quenching, and after cooling to 600° C. at a rate of 50° per minute and then quenching are shown in Figs. B, C, and F, respectively, of Plate VIII. The numerous parallel bands of Fig. B have given place to a more scattered form of Beta (in more or less discontinuous patches) in Figs. C and F. As previously explained, this has a greater effect on the reduction of area than on the elongation.

Incidentally, Figs. C and F of Plate VIII. illustrate one of the many comparisons which may be made to show the structural

* In the case of Alloy II, changes were marked at the lower temperatures even during cooling at the slower rates. We have dealt with this condition in an earlier discussion.

identity of alloys in which the same mechanical properties have developed as a result of heat treatments combining different rates of cooling with different quenching temperatures. Here, Alloy III cooled at a rate of 20°C. per minute to 650°C. and quenched gives tensile strength, elongation, and reduction of area values of 53,300 lb. per sq. in., 66 per cent., and 55 per cent., respectively ; while the same alloy cooled at a rate of 50°C. per minute to 600°C. and quenched gives corresponding values of 53,250 lb. per sq. in., 67 per cent., and 56.9 per cent. The correlation of structure and properties is thus seen to be very satisfactory.

Finally, it may be noted that while the ultimate value of elongation obtained by cooling at a rate of 50°C. per minute is about the same as that obtained by cooling at the much slower rate of 20°C. per minute, it is necessary that the entire cooling range, 700° to 450°C. , be utilized in order to bring the elongation up to a maximum value at the faster rate. If as rapid a rate of cooling as 50°C. per minute is attained in the commercial annealing of Muntz metal, great care should be taken that the cooling be allowed to proceed unchecked to very low temperatures ; otherwise, a low order of ductility will result.

Table XI. contains the data from tests on strips which we endeavoured to cool at an average rate of 100°C. per minute to indicated quenching temperatures. As shown in the table, the actual average rate of cooling of the different strips varied from 86° to 110°C. per minute and, in addition, great irregularities attended the cooling of each pair of strips.

While the results are not comparable in accuracy with those obtained in the previous tests, they indicate (1) that the elongation of Alloy I or Alloy III varies only five or six percentage units between the maximum and minimum quenching temperatures and the tensile strength only two or three thousand lb. per sq. in. ; (2) that this rapid rate of cooling is effective in raising the reduction of area of Alloy III ; and (3) that the ductility of Alloy II is subject to a much greater change as a result of this treatment than the ductility of either Alloy I or Alloy III, which is of course evidence in support of the view that readjustment affecting the quantities of Alpha and Beta is more easily attained in Alloy II than in the other alloys.

For purposes of comparison, a photomicrograph representing

TABLE XI.—Testing Data showing the Effect of Cooling at a Rate of 100° C. per Minute to Indicated Quenching Temperature after 15 Minutes' Annealing at 700° C.

No. of Test.	Grade* of Material.	Quenching Temperature, C.	Average Rate of Cooling, Degrees per Minute.	Tensile Strength, Lbs. per Sq. In.	Reduction of Area per Cent.	Elongation per Cent. in 2 Inches.
173	I	650		52,400	56.00	55.00
174	I	650		52,800	56.10	58.00
		Average	90	52,600	56.05	56.50
175	II	650		61,600	43.30	49.00
176	II	650		62,000	40.60	45.00
		Average	86	61,800	41.95	47.00
177	III	650		54,900	55.00	56.00
178	III	650		54,900	55.00	56.00
		Average	90	54,900	55.00	56.00
179	I	600		52,600	56.60	55.00
180	I	600		53,500	56.40	57.00
		Average	100	53,050	56.50	56.00
181	II	600		59,700	41.20	50.00
182	II	600		59,000	49.50	56.00
		Average	100	59,350	45.35	53.00
183	III	600		53,200	55.80	60.00
184	III	600		53,300	55.30	57.00
		Average	94	53,250	55.55	58.50
185	I	550		51,400	56.80	57.00
186	I	550		51,500	56.80	57.00
		Average	110	51,450	56.80	57.00
187	II	550		58,400	50.20	57.00
188	II	550		58,450	50.20	57.00
		Average	95	58,425	50.20	57.00
189	III	550		52,700	57.50	66.00
190	III	550		52,750	57.50	68.00
		Average	108	52,725	57.50	67.00
191	I	500		51,700	57.90	63.00
192	I	500		51,900	57.70	62.00
		Average	98.5	51,800	57.80	62.50
193	II	500		58,300	51.50	58.00
194	II	500		58,300	51.50	58.00
		Average	92.5	58,300	51.50	58.00
195	III	500		51,400	57.50	62.00
196	III	500		51,700	58.30	64.00
		Average	104	51,550	57.90	63.00
197	I	450		50,900	57.80	59.00
198	I	450		50,500	57.80	61.00
		Average	94	50,700	57.80	60.00
199	II	450		57,600	51.00	64.00
200	II	450		57,600	51.50	57.00
		Average	98.4	57,600	51.25	60.50
201	III	450		51,700	58.00	64.00
202	III	450		51,800	58.10	65.00
		Average	102	51,750	58.05	64.50

* Composition of Alloys.

No.	Per Cent. Copper.	Per Cent. Zinc (difference).	Per Cent. Arsenic.	Per Cent. Iron.	Per Cent. Lead.
I	62.41	37.514	0.024	0.03	0.022
II	61.07	38.675	0.139	0.03	0.086
III	62.49	37.343	0.120	0.03	0.017

the structure of Alloy III after cooling to the lowest quenching temperature at the present rate of 100°C. per minute (Fig. F) is placed alongside of others in Plate VII. representing the structure after cooling to the same temperature at a rate of 50°C. per minute in one case (Fig. E), and at a rate of 20°C. per minute in the other (Fig. D). It is quite apparent that a considerable quantity of Beta is retained in the form of a network after cooling at the maximum rate, while small but approximately the same quantities of Beta remain after cooling at the two slower rates. This is what would be expected in view of the low ductility of the first alloy and the materially higher, but nearly equal ductilities of the other two alloys.

V. GENERAL COMPARISONS FROM THE STANDPOINT OF COMPOSITION.

With respect to the influence of some 0.14 per cent. of arsenic on the mechanical properties of alloys containing about 62.5 per cent. of copper, after annealing and quenching at a variety of temperatures between 450° and 750°C. , it may be said that greater elongation and greater strength were consistently obtained in the case of the arsenical test-strips. After annealing and quenching at 550°C. , the temperature which develops maximum values of elongation and minimum values of tensile strength in both cases, the arsenical metal possessed an elongation of 77.5 per cent. in 2 inches and the non-arsenical metal an elongation of 74.25 per cent. ; while the arsenical metal possessed a tensile strength of 49,300 lb. per sq. in. and the non-arsenical metal a tensile strength of 48,300 lb.

The ductility, as measured by percentage reduction of area, is about 14 percentage units lower in the case of the arsenical metal after treatment at 700° or 750°C. Thus, the arsenical metal appears to be influenced more seriously than the non-arsenical metal by what may be characterized as improper annealing treatment, i.e., annealing at high temperatures, followed by immediate cooling at a quenching rate. If the cooling is reasonably slow, as should always be the case, a perfect recovery of ductility, as measured by reduction of area, takes place —

even when slow cooling is superseded by quenching at dull red heat.

Comparisons with respect to variation of the copper-content were made on the basis of the arsenical alloy containing 62.5 per cent. of copper and another containing 61 per cent. of copper. Corresponding to the difference in copper-content of 1.5 percentage units and perhaps in part to the somewhat higher lead content of the latter alloy (0.086 per cent., as compared with 0.017 per cent. in the former alloy), the maximum value of elongation—obtained after treatment at 550° C.—was 15.25 percentage units greater in the case of the former alloy and the minimum value of tensile strength, 6,650 lb. per sq. in., greater in the case of the latter alloy. Corresponding differences were obtained at other annealing (and quenching) temperatures.

With respect to alloys cooled to different temperatures at rates varying between 5° and 100° C. per minute, after a preliminary anneal of 15 minutes at 700° C. the arsenical metal containing 62.5 per cent. of copper again shows generally higher values of elongation than the non-arsenical metal of the same copper-content. This is true whatever the rate of cooling, or the point at which cooling at a given rate is arrested by quenching. We have already stated that low values of reduction of area brought about by quenching the arsenical metal at 700°, or 750° C., are readily brought to normal values by cooling at almost any rate short of quenching after the annealing treatment.

The effect of decreasing the copper-content by 1.5 percentage units on the properties developed by cooling at various rates after anneal at 700° C. lies principally in the direction of decreasing the difference of elongation originally seen in the two quenched alloys, i.e., the difference before cooling at a given slow rate. Differences of tensile strength and reduction of area remain relatively the same after a given form of treatment. Obviously, the variety attained in this work was sufficient to preclude any adequate statement of results in brief form.

In general, it may be said that metal of the present character made from arsenical copper is likely to afford a better combination of strength and ductility than metal made from electrolytic copper when both are properly annealed.

VI. GENERAL COMPARISONS FROM THE STANDPOINT OF HEAT TREATMENT.

Tests on all three alloys after annealing and immediate quenching at various temperatures, the material having previously been hot-rolled, annealed with slow cooling, and then cold-rolled to a 50 per cent. reduction, shows clearly that the maximum elongation and the minimum tensile strength are developed in all cases after anneal at incipient red heat.

If, however, we take into consideration the effect of slow cooling, it is necessary to distinguish between results obtained with the alloys containing 62.5 per cent. of copper and those obtained with the alloy containing 61 per cent. of copper. In the former case, the slowest rate of cooling adopted in these tests, viz., 5°C. per minute, when carried down to 450°C. , after preliminary annealing at 700°C. , failed to yield as high a value of elongation as that developed by the simple anneal with quenching at 550°C.

Thus when a high requirement of ductility is to be met the cold-rolled alloys containing 62.5 per cent. of copper may be annealed at incipient red heat with little regard to the subsequent rate of cooling.

In the case of the alloy containing 61 per cent. of copper, an anneal at 700°C. , followed by slow cooling to 450°C. , gives greater ductility than does annealing followed by immediate quenching at the most favourable temperature (550°C.).

Considering the effect of the various rates of cooling on either the arsenical or the non-arsenical brass containing 62.5 per cent. of copper, the slowest rate, namely 5°C. per minute, leaves the alloy with a maximum of ductility (72–75 per cent. elongation in 2 inches), and this maximum is reached by the time the metal has cooled to 550°C. ; the next rate in order, viz., 20°C. per minute, leaves the metal with a ductility some 4 or 5 percentage units below that in the previous case and this value is also reached by the time the metal has cooled to 550°C. ; the next rate in order, viz., 50°C. per minute, leaves the metal with about the same ductility as in the previous case, but cooling in this case must be continued to 450°C. ; and the final rate adopted, viz., 100°C. per minute, produces little change in ductility.

Considering the effect of the above rates on the single alloy containing 61 per cent. of copper; the 5° rate develops a maximum of ductility (about 60 per cent. elongation in 2 inches); the 20° rate develops the ductility to within some 3 percentage units of the previous value; the 50° rate develops about the same degree of ductility as the 20° rate; and the 100° rate develops the ductility to within some 6 percentage units of the last value. In all cases, the ductility changes noticeably throughout the entire cooling range and the above summary is based upon cooling at the specified rate from 700° C. to 450° C.

From these considerations, it may be argued that in order to obtain the most favourable conditions for cold-working a brass containing 61 per cent. of copper (and this probably applies to ordinary Muntz metal containing 60 per cent. of copper), annealing, if conducted at temperatures above moderate red heat, should be followed by at least a moderately slow rate of cooling, say 20° C. per minute, and slow cooling should be continued to a temperature not far above 450° C.

If the metal is higher in copper, viz., if it contains some 62 to 63 per cent. of copper, emphasis should be laid on very slow cooling; for example, a 5° rate is far more satisfactory than a 20° rate, and in such case the metal should be allowed to cool normally to some 550° C., whereupon it may be quenched in a stream of water if desired. In case a rate of cooling in excess of 20° C. per minute prevails, it will be advantageous to allow such cooling to proceed unchecked to 450° C., or even a lower temperature.

DISCUSSION.

The PRESIDENT said that it afforded him much pleasure to ask Dr. Hudson to open the discussion upon the important paper that had just been read. As most of the members were aware, Dr. Hudson had done a great deal of work in conjunction with Captain Bengough on the particular subject dealt with in the paper. The members would probably be interested to know that those two investigators were now working, in the service of the Institute, in connection with the re-formed Corrosion Committee. A grant of £900 had been given by the Privy Council Committee on Research for the prosecution of the work, and a new sea-water station was being established at Brighton, Dr. Bengough being at present engaged in getting the station into working order.

Dr. O. F. HUDSON (London), in opening the discussion, said that he had read the paper with very great interest, and desired to record his admiration of the very valuable record of careful investigation on the effect of heat treatment on the tensile properties of alloys that it contained. The paper was particularly valuable in that it gave an account of the systematic and accurate heat treatment to which the alloys were subjected. The temperatures were accurately controlled, and the quenchings were carried out in a systematic manner. He was a little doubtful whether the tests went far enough to establish complete confidence in arsenical brass. The tensile tests showed that such brass could be satisfactorily worked both hot and cold to give a material having good tensile properties; but it occurred to him that to study completely the effect of arsenic on the annealing properties further mechanical tests, for example, shock tests, should be carried out. He was sure all the members would agree with him that the photomicrographs were most excellent; they very closely followed the changes that took place in the mechanical properties. The only criticism he desired to make with regard to the photographs themselves related to the magnifications. He noticed that the magnification of most of the photographs was given as 76. That seemed to him a number that might have been improved upon. He did not know why such a magnification was given; there might be very good reasons for its use so far as convenience was concerned, but he thought there was no real difficulty in taking all photographs at some standard magnification, say 100 or any other figure that might be decided upon. He suggested that the question of the standardization of the magnifications of all photographs that were reproduced should be taken in hand.

The SECRETARY, interpolating, stated that the Publication Committee had a scheme for effecting such a codification of magnifications as Dr. Hudson suggested, but unfortunately the Authors were not aware of it when the work was done.

Dr. HUDSON, continuing, said that he was not sure that the banded structure which was shown so clearly in some of the photographs was a common phenomenon in the case of pure alloys. As the Authors pointed out, it was particularly marked in the arsenical brasses. His own impression was that it was not frequently met with in pure copper-zinc alloys of that composition. No doubt it depended very largely on the size of the section rolled. There were two rather incidental points to which he desired to refer, the first being the influence of arsenic in retarding diffusion of crystalline growth. Such an effect would probably be found with many impurities. He referred to the microstructure of copper-zinc-nickel alloys, where the nickel played such a very important part in hindering diffusion in the alloys. Finally, there was the question of laminar structure observed in the beta constituent. Such a structure, resembling a laminar structure, could be obtained from the Beta constituent when the excess Alpha crystallized out. He remembered obtaining structures that were distinctly laminar not from 60 : 40 alloys but from others containing slightly higher zinc, but such a laminar structure could be very plainly seen at a magnification of 100 diameters. Although he had examined a very large number of alloys, containing the Beta constituent, with high magnifications, he had never been able to obtain a finely laminar structure such as the Authors referred to; and it would be of great interest if they could give a photograph of such a structure.

Mr. THORNTON MURRAY, M.Sc. (Birmingham), thought that the Authors deserved the thanks of the sheet rolling trade for the valuable addition to the metallurgical knowledge of the behaviour of alloys of the Muntz metal type, more especially in regard to the annealing and heat treatment of the metal, that was given in the paper. Many of the results obtained were susceptible of direct practical application, particularly the work on the influence of cooling velocity on the physical properties. In that connection the information with respect to the non-arsenical alloy had an interest as great as, if not greater than, that dealing with the arsenical alloy, in that much of the knowledge gained was entirely novel; while the correlation of physical properties with structural changes, a point too often neglected in similar academic researches, was most helpful to the practical worker in metals. In view of those considerations, it was therefore somewhat unfortunate that variations occurred, supposedly difficult of avoidance, in the composition of the alloys tested, notably in the lead content of the strips and in the arsenic content of the "Standard Alloy No. 1." This figure varied considerably. In one case it was 0.08 per cent.; in

another case 0.017; and in another 0.022. In one case it was nearly four times as great as in the other; in one case it was more than four times as great. Further, the No. I alloy, which was supposed to be the standard alloy, contained 0.022 per cent. of arsenic. That he regarded as unfortunate, a fact to which he would call attention later on. He quite understood that the arsenic might have crept in from the use of arsenical scrap, but he thought it was a great pity that care was not taken that electro-copper only was used in making this alloy. Comparative tests of an alloy made from electro-copper and relatively pure spelter, of a similar content to that of No. II, would also have been of value, as that alloy approximated in composition more nearly than either of the others to the alloy generally used for hot-rolling in this country. He thought it was rather a pity that the No. II alloy, the 61 per cent. alloy, also free from arsenic, was not included in the research and dealt with upon the same lines as the Authors had dealt with the other material, because it would have given very interesting information. The arsenical portion of the paper was particularly opportune at the present juncture, when economic considerations were compelling the manufacturer to use copper or ingot brass of doubtful antecedents. His own experience had been that one of the most frequent impurities in copper and even brass scrap was arsenic. That was probably due to carelessness in handling, giving rise to the mixture of arsenical copper scrap with copper scrap free from arsenic.

He desired to confess at once that his experience with arsenical brass had contained little to make him enamoured of the material. He was speaking, however, of the ordinary English mixture of hot-rolling brass (or cold-rolling brass of the Muntz metal type), which generally, being made with a relatively impure spelter, carried lead in proportions up to 0.5 per cent. or even 1.5 per cent. It might be noted that the alloy investigated by Dr. Bengough and Dr. Hudson in their classic work on the heat treatment of the copper-zinc alloys contained 60.43 per cent. copper and 0.33 per cent. of lead, an alloy much more typical of British rolling practice than any of those investigated by the Authors of the present paper. That of course was not their fault; it was due to differences between American and British methods of brass sheet rolling. It had been his experience that sheets hot-rolled from lead-bearing metal containing arsenic, the latter even in quantities slightly below 0.1 per cent., had proved very unsatisfactory in practice, giving, both in the hard and in the annealed condition, very low figures for both tensile strength and elongation. He had, however, found that more prolonged annealing at 650° C., together with very slow cooling, had largely remedied the lack of ductility, as measured by elongation, though the strength of the metal was, as might have been expected, not greatly improved by that treatment. By that he meant that the prolonged annealing had caused a large crystal growth, and that had more or less militated

against a high tensile strength. Such sheets, however, had never, so far as he was concerned, given as good results, either in testing or in subsequent use, i.e. cupping, spinning, &c., cold, as sheets free from arsenic or containing less than, say, 0.03 per cent. of arsenic. It must be understood that he was speaking of lead-bearing sheets, hot-rolled, with a copper content of a little below those of alloys I and II. He had had no experience of hot-rolling on a large scale arsenical sheets which contained lead only to the extent of less than 0.1 per cent. With less than 0.03 per cent. arsenic he had found the effect even on a lead-bearing brass rather beneficial than otherwise. He believed attention was originally drawn to that fact a very long time ago by Sperry, who pointed out that with less than 0.02 per cent. of arsenic the brass was better, so far as tensile strength and elongation were concerned, than an absolutely pure brass, and the incidental experience which he (the speaker) had gained in dealing with arsenical material had more or less borne out that statement. The increase of arsenic content, however, due to scrap returns—a point the importance of which practical men would at once realize—had taught him by bitter experience to have nothing to do with copper containing arsenic, where the copper was destined to be used in the manufacture of brass. One could have wished, in the light of the above fact, that the Authors had been able to extend their research in the direction of slightly higher arsenic contents than those dealt with in the paper; while a further examination of the effect of arsenic, together with lead, on Muntz metal would probably throw an interesting light on the cause of failure of that class of metal. He trusted that at some time in the future it would be possible to have a research in that direction carried out in this country. Dealing with the first series of tests given in the paper, i.e. annealing at various temperatures and quenching from them, the maximum in elongation at 550° C. was very interesting, and the Authors' explanation of it was no doubt right, particularly in view of the differences in commencement of recrystallization of the Alpha grains, and possibly the Beta grains, between arsenical and non-arsenical brass. Translated into non-technical language, might this be taken to mean that the annealing for relief of work-effect, i.e. to enable granular recrystallization to take place, should be more prolonged in the case of large bodies of arsenical brass than in the case of similar masses of pure brass? His own experience in practice certainly bore that out. He wished that some photomicrographs had been taken at higher magnifications—quite apart from the interesting point which Dr. Hudson had raised with regard to the standardization of magnifications—especially with a view to closer examination of the structure of the Beta constituent in the alloys quenched from temperatures above, say, 470° C., as compared with those slowly cooled through that temperature. There was no mention made of the change point of Beta into Beta', or Alpha plus Gamma, at 460°–470° C., and the effect, if any, of the arsenic upon that point in the particular circumstances of the

research. Possibly, too, the somewhat violent etching agent used had served to darken the Beta too much for close examination of its structure to be possible. Turning to the latter part of the paper, i.e. that section dealing with rates of cooling, the curves shown were more or less what would have been expected in the circumstances, and certainly agreed well with the microstructures illustrating them. There was one point, however, which was perhaps worthy of note. In the preliminary annealing for one hour at 650°C ., followed by very slow cooling at 2° per minute down to 300°C ., it might have been expected that the material would have developed, as was intended, its maximum ductility, but unfortunately it did not. It was found that neither the ductility nor the strength of any of the alloys was in that case equal to that obtained by annealing at 700°C . for 15 minutes and cooling at 5° per minute. That was particularly marked in the case of Alloy No. II (61 per cent. copper). Were they to suppose that the period of annealing in that case was too long, that it led to too great a crystal growth, or that in the subsequent annealing experiments the time of annealing, 15 minutes, was insufficient to neutralize the effect of the cold-rolling on the specimens? Or might it be that the rate of cooling, 2° per minute, was too slow for the material in question, allowing, as it probably would, of the attainment of almost complete equilibrium conditions? Or again, were the reduced elongation and tensile strength due to slow cooling to a lower temperature than was allowed in the case of the other alloys, possibly involving the completion of the 460° reaction, or slow cooling to below the brittle range of the metal? At any rate, that was a point which might well be cleared up, as a 2° per minute rate of cooling was by no means abnormally slow in practice, an even slower rate often obtaining where the pack system of annealing sheets was in vogue. Very often sheets were cooled down at the rate of 1° per minute. He also desired to point out that in works practice, generally speaking, the cooling after annealing was by no means regular, and therefore he failed to see why the Authors went to such very great pains to obtain a regular rate of cooling in their experiments. In practice the cooling in the higher ranges was probably very much faster than in the lower. In conclusion, he desired to make it quite clear that some of the criticisms he had made, notably in regard to the lack of information concerning lead-bearing brass, were by no means to be taken in the light of strictures upon the paper, which it was fully realized dealt very ably with some of the problems arising from the methods practised in the American trade, but were rather intended as an incentive to some of our research metallurgists to attack similar problems with which the brass sheet manufacturer in this country was almost daily brought into painful contact. They might do a great deal worse than model their investigation upon the lines followed by their American friends in the paper. He wished to add an additional note on the fracture of arsenical Muntz metal, as it embodied a little experience he had obtained in regard to arsenical

brass. When he had discovered, to his own satisfaction at least, that arsenic was injurious to the particular grade of metal that his firm made, he cast about for a rapid "shop" method of discovering its presence in the brass or copper used for making the brass. It was found that the ordinary Muntz metal fracture test, a very old-fashioned, but, in its way, useful test, gave, with certain limitations and within certain limits, an excellent indication of the presence of arsenic. He had brought a few specimens with him in the hope that the phenomenon might be new to at least some of the members. Captain Bengough had seen them in their laboratory and was very much interested in them. There were four of the test-pieces. It might be noted that the lead-free, i.e. lead content less than 0.1 per cent., brass gave the most striking fracture in the presence of arsenic, while the presence of lead in others to a certain extent masked the effect, although the injurious effect of the impurity on the physical properties of the metal was, if anything, exaggerated by the presence of the lead. In the lead-free tests it was found, using lead-free spelter, electro-copper and metallic arsenic, that arsenic in percentages in the brass of up to 0.05 per cent. gave little or no indication of its presence, but that any larger proportion immediately made itself obvious. In the lead-bearing brasses the same figure held good, but the appearance was much less striking and might often be passed over. A moral to be drawn from that fact was that only relatively pure spelter should be used in making a Muntz metal test. Arsenical Muntz metal in rolled sheet, rod, or plate, showed the usual finely granular fracture, without yellow streaks, as in the cast test-pieces, but was of a canary yellow all over, instead of the usual grey colour. The effect was quite easy to see. Finally he would say that if any of the members thought of taking the paper, excellent though it was, as a criterion of what was going to happen to lead-bearing brasses of the Muntz metal type with arsenic in them, and proceeded to manufacture on that basis, they would find out their mistake in a very short time.

Professor T. TURNER, M.Sc., Vice-President, said that when he first read the paper it struck him as a very admirable example of how a practical problem should be studied, and he thought the paper should be judged chiefly from that standpoint. When articles requiring a good deal of cold work had to be produced from an arsenical copper, it was necessary to study, by a series of scientific tests, what the effect of that impurity would be. He did not remember reading in the paper any statement to the effect that the metal ultimately did or did not cup well, and that the practical work tests agreed with the tests of elongation and of reduction of area. Presumably that was so, but it would be well if a statement were made in the paper to that effect. Dr. Hudson had voiced the same doubt when he said that it would be well if some shock tests or alternating tests of the metal were given in addition to those embodied in the paper. He also had the feeling.

which had been partly mentioned by Mr. Murray, that from a scientific point of view one would have liked the series carried a little further, starting in the first place with no arsenic; having several more alloys than were experimented with, and carrying the percentage of arsenic higher. Many of the results that had been obtained were such as would be expected from the addition of another element, especially one like arsenic, which in small quantity went into solution. The tensile strength at all events would be expected to increase; but he did not know that he would have expected, apart from certain points that were raised in the paper, that the ductility would also be increased at the same time. Still there were other examples, such as that of nickel in steel, where it was possible to have a solid solution with increased tenacity without the ductility falling off, as was usually the case with a solid solution. It was perfectly obvious that the percentage of arsenic that could be used with advantage, even from a scientific point of view, could not be very large, on account of the high melting point of the compound of zinc and arsenic. The annealing tests, as Mr. Murray had already partly pointed out, gave conclusions in the first place such as would be anticipated from hard-rolled material. When hard-rolled material was annealed the tenacity fell and the ductility increased. It was, however, a surprise to him to find that on further annealing the tenacity increased; and he presumed that if the alloys were used in practice that fact would be taken advantage of. He felt that as an Institute the members were fortunate in having such a paper presented to them, despite the limitations which applied to it so far as some of the points to which he had referred. Some of these limitations would apply to all papers; and he thought that on the whole the present paper could be taken as a model of the type of paper which it was desirable to have. It embodied the results of a research undertaken by men who, on the one hand, were familiar with the scientific aspects of the question, i.e. with the bearing of the equilibrium diagrams, the microscopic tests, and the chemical tests; and who, on the other hand, carried out practical work and had to tackle the commercial question. The combination of science with practice was a feature which the members knew the Institute desired, but which they were told they sometimes did not appreciate.

Dr. W. ROSENHAIN, F.R.S., Member of Council, thought that the paper might be regarded as the beginning of a systematic research in regard to the influence of impurities on brass. As such, he particularly appreciated it, because he had himself put forward the proposal that—with the aid of the Council for Scientific and Industrial Research and under the auspices of a Research Committee of the Institute of Metals—this subject of the influence of impurities on copper and its alloys should be systematically investigated. The only point to which he desired to refer in any detail was the question of the banded structure. He was very much interested in that, because there was an interest-

ing analogy in the behaviour of phosphorus in steel which also distinctly favoured the production of a banded structure, and for a precisely similar reason—that either the phosphorus diminished the rate at which carbon would diffuse into iron or it diminished the solubility of carbon in iron. It was just possible that the latter was the real cause of this action of the arsenic also—that the presence of arsenic might actually diminish the total solubility of zinc in copper. That was a point which ought to be cleared up in a complete study of the whole question. Very possibly the facts stated by Mr. Murray, that the presence of lead and arsenic simultaneously might set up a totally different state of affairs from what existed with arsenic in the absence of lead, might find a similar explanation. The question of the solubility of lead in Beta was incidentally referred to by the Authors; it was more than likely that the question of whether arsenic was present, and how much there was present, would influence the amount of lead which would go into solution in Beta, and that would materially affect the properties of the resulting brass. He was not therefore in the least surprised to find that practical experiences with brass containing arsenic plus lead were quite at variance with the results obtained by the Authors.

Some of the Authors' experimental methods might be referred to a little critically. He was not at all convinced, for instance, that the temperatures which they obtained by placing their thermocouples in the V formed by two strips of brass were really anything like within 5° of the true temperatures of the metal. Further, they made their tests with very thin sheet brass, in some cases as thin as 0.015". The test-pieces were exposed to a temperature as high as 700° or 750° C., having apparently been machined to size, and they were then tested without any further treatment. He did not know whether any allowance was made for the reduction of thickness due to the scaling which would undoubtedly occur. They did not give any particulars on that point, and he thought there was a certain amount of opening for criticism or at any rate a little doubt in that respect. Having neglected those factors, the Authors proceeded to make comparisons down to a few hundred pounds per square inch. Personally he felt inclined to take the view right through that the Authors were building a little too much on the data they had obtained. Admittedly they had made only a limited number of experiments; they stated that only a limited number were made because they wished to finish their research in a reasonable time; but the net result was that the Authors were undoubtedly building a great deal on somewhat slender data. A point in that connection occurred to him where they emphasized the crossing over of the elongation curves. It was quite a minor point, but it was indicative of what he had in mind. It would be seen in Fig. 2 that the elongation curves crossed, but it would be noticed that the distance apart of the two points on which that crossing was based was rather less than the distance of several of their other points from the curve

to which they belonged, so that the curves could quite well have been drawn without crossing. But detailed criticism of that kind was perhaps hardly necessary. As a preliminary study of a subject which was of very great and increasing importance, the paper was undoubtedly most valuable and welcome, and he was sure the members hoped the Authors would carry their work further, and give them the benefit of it.

Professor A. K. HUNTINGTON, A.R.S.M., Past-President, emphasized the point that the paper was an admirable one, and that it pointed very clearly to the direction in which further work was much required. The particular amount of arsenic present in the metal referred to in the paper apparently gave a satisfactory result, or at any rate it must be assumed that the cupped metal was satisfactory as it left the works. He did not know how long it had been in use, and the question remained whether something might not happen later on. Assuming that that amount of arsenic was satisfactory for the composition in question, it was apparent from what other speakers had said that there was very little doubt that the presence of quite a minute quantity of some other metal, say lead, would materially alter the whole condition of affairs. That raised the point that a very large number of experiments needed carrying out, entailing an enormous amount of work, and it was quite certain that the work was required and that it should be done. In his opinion it was the kind of work which the Advisory Council for Scientific and Industrial Research of the Privy Council should be asked to assist in organizing and financing, and in fact they had already been asked to make a beginning in that direction. It was work that it was exceedingly difficult for any private laboratory to carry out, in its entirety at any rate, and it might be taken for granted that works laboratories would not undertake such a gigantic task. It required to be thoroughly organized and carried out, and in his opinion it could be very well done through the Advisory Council. He thought the paper was very opportune for that reason, the time being ripe for dealing with the subject in some such way; in fact, it was the only possible way to deal with it. He thought the members were very much indebted to the Authors for placing their conclusions before them, and they were deserving of the thanks of the Institute for the very able way in which they had carried out the experiments so far as they had gone.

COMMUNICATIONS.

Dr. CECIL H. DESCH (Glasgow) wrote that the interesting banding observed by the authors in the arsenical brass pointed to marked segregation of arsenic in the original ingot, and it would be of interest

if additional photographs could be shown, representing the metal before rolling. If, as appeared likely, the segregation in the ingot should be considerable, it might be expected that the proportion of arsenic in different bars rolled from the same ingot would not be quite the same.

Mr. F. JOHNSON, M.Sc. (Birmingham), wrote that he was much interested in the subject of annealing arsenical brass, particularly as the influence of arsenic in copper alloys had engaged much of his interest and attention. The authors seemed to have ignored a paper by E. A. Lewis* in which brasses of varying copper contents were compared for rolling properties with similarly composed brasses containing a small quantity of arsenic. Lewis's experiments did not go very far, but they brought out the fact that a small quantity of arsenic had no detrimental influence on brasses for rolling. The results obtained by Lewis were as follows :

No.	Copper per Cent.	Arsenic per Cent.	Ult. Tensile Stress per Sq. In.		Elongation per Cent.		Reduction of Area per Cent.
			lb.	tons.	on 1"	on 4"	
1 unannealed	61.44	0.065	80,915	36.10	16.5	5.6	32.4
5 "	61.90	nil	79,175	35.30	17.0	6.75	45.75
2 "	67.43	0.068	68,400	30.50	23.5	7.00	43.20
6 "	67.01	nil	69,825	31.20	22.0	6.40	43.40
3 "	69.97	0.068	70,950	31.60	22.0	6.50	43.40
7 "	69.52	nil	71,700	32.00	20.0	6.00	41.30
4 "	74.60	0.068	72,475	32.30	25.0	7.60	45.70
8 "	74.56	nil	73,100	32.60	22.0	6.35	45.00
1 annealed	61.44	0.065	50,200	22.40	60.0	43.50	54.10
5 "	61.90	nil	49,450	22.10	64.0	48.25	55.85
2 "	67.43	0.068	44,700	19.95	79.0	61.00	61.20
6 "	67.01	nil	43,770	19.55	72.0	57.50	60.45
3 "	69.97	0.068	44,000	19.65	77.0	60.00	62.75
7 "	69.52	nil	43,600	19.50	78.0	57.75	61.15
4 "	74.60	0.068	44,100	19.70	78.0	57.75	61.50
8 "	74.56	nil	44,125	19.70	74.0	58.75	60.90

In an article in "Engineering" † which appeared at the same time as that by Lewis, he (Mr. Johnson) had described some experiments which he had carried out on brass of 60 : 40 composition. The object of the experiments was to determine whether arsenic, antimony, or bismuth alone was responsible for the yellow streak which appears in the fracture of impure Muntz metal. It was found that no yellow streak was obtained with arsenic alone up to 0.6 per cent., nor with bismuth alone up to 0.31 per cent., nor with antimony alone up to at least 0.1 per cent.

When arsenic and antimony were introduced together, however,

* *Metal Industry*, vol. v. 1913, p. 96.

† *Engineering*, vol. xcv. p. 283.

the combination was very injurious, a "streaky" fracture being obtained with as little as 0.03 per cent. antimony and 0.03 per cent. arsenic.

The hot-forging and cold-rolling properties appeared to be only slightly affected up to the quantities mentioned. The composition of one of the alloys containing arsenic and antimony was as follows :

	Per Cent.
Copper	60.80
Zinc	38.61
Lead	0.43
Iron	0.08
Arsenic	0.04
Antimony	0.04

The compositions of the other alloys were very similar, the additional elements, arsenic, antimony or bismuth displacing an equivalent proportion of zinc.

Antimony was more powerful than arsenic in producing the "streaky" or coarsely crystalline fracture.

There were one or two points in the authors' paper to which he (Mr. Johnson) would like to refer. On page 27 the authors pointed out that the elongation of test-strips was measured on a length of 2 inches. He (Mr. Johnson) would prefer to have seen the elongation measurements made on a length having a constant ratio to the sectional area.

In testing brass strips he had noticed repeatedly that if a standard length were adopted, the elongation fell off materially the thinner the strip.

By using a ratio such as

$$\frac{l}{4} = \sqrt{\text{area}}$$

where l = gauge length, the elongations for any given material were much more comparable. The elongation results in Table IV. would be more comparable if some such standard ratio had been adopted.

With reference to the etching method adopted (see p. 38) he (Mr. Johnson) could testify to its usefulness. He had, however, been in the habit of darkening with ferric chloride and then subjecting the surface to a light polish attack, using calcined magnesia on parchment moistened with dilute ammonia.

The authors referred several times to the absorption of Beta by Alpha, but, as had been shown by Hudson, the reverse was true. The relatively greater proportions of Beta at high temperature were super-saturated with Alpha, which crystallized out as the temperature fell. Muntz metal itself at normal temperature was a conglomerate of Alpha and Beta, but immediately after solidification consisted entirely of Beta, from which Alpha crystallized out on cooling. An increase in the proportion of Beta by raising the temperature was brought about by the absorption of Alpha. He (Mr. Johnson) could not agree with the authors' interpretation of the elongated bonds of Beta (p. 43) as not

having been produced by the rolling operation, nor that such bands after being removed by annealing could be redeveloped by further annealing.

On p. 46 the authors referred to the "finely lamellar internal structure" of the quenched Beta phase. In a paper read before the Institute,* he (Mr. Johnson) had pointed out the same thing, viz.: that alloys containing from 60 to 63 per cent. copper when quenched (just below the solidus) showed a minutely duplex structure.

He was in agreement with the authors' interpretation of this structure. Finally, it appeared to be a curious inconsistency that the authors should lay emphasis on the necessity for very slowly cooling the softer alloy (containing 62 per cent. to 63 per cent. copper), p. 65, after pointing out, p. 64, that the cold-rolled alloy containing 62.5 per cent. copper may be annealed at incipient red heat with little regard to the subsequent rate of cooling when a high requirement of ductility is to be met."

Professor MATHEWSON wrote in reply to the verbal and written discussion of his and Mr. Thalheimer's paper that he desired to thank the members for their cordial reception of the paper and for courtesies on the part of officers of the Institute incidental to publication of the paper in the Journal.

The authors shared Dr. Hudson's opinion that to study completely the effect of arsenic on the annealing properties further mechanical tests should be carried out. Doubtless most authors who had undertaken research of this character felt more or less the limitations imposed by certain conditions and were often compelled to sacrifice outgrowing matters of great interest owing to pressure of work, lack of facilities, lack of material or other untoward circumstances. The authors were in sympathy with attempts to establish a set of standard magnifications which would appeal universally. Certain magnifications had become common in brass laboratories of the various plants in this vicinity and the intimate relations between the Hammond Laboratory and several of these plants were largely responsible for the magnifications used in the present paper.

The authors thought that a strongly banded structure would be encountered in Muntz metal alloys in which the copper-content and the temperature of hot-rolling were such that fairly equal quantities of the Alpha and Beta constituents were present during the principal extension of the piece and that no subsequent heat treatment sufficed to cause nearly complete disappearance of one or the other constituent; under ordinary conditions annealing at a high temperature (within the field of homogeneous Beta) would, of course, obliterate the banded structure and cause equiaxed Alpha to appear on cooling, while a prolonged annealing at low temperature would alter the banded

* *Journal of the Institute of Metals*, No. 1, 1912, vol. vii. p. 206.

structure to a certain extent by causing absorption of Alpha, viz., partial destruction of the Alpha bands.

Dr. Hudson's remarks relative to the effects of arsenic, nickel, or other added elements in hindering diffusion were highly appropriate, but it might be emphasized that the drastic annealing treatment required to homogenize an ordinary nickel-silver is far in excess of that required to produce the same effect in an arsenical brass of the present type. The authors regretted that the need for an immediate reply to the discussion made it impossible to prepare a micrograph illustrating the lamellar structure in the quenched Beta phase. Mr. F. Johnson was in agreement with the authors with respect to this observation, although Dr. Hudson had not made it in his experience. Messrs. Stead and Steadman, in a paper read before the Institute,* had made substantially the same observation. The authors had not studied this question in detail, but thought that a wide range in the size of Alpha particles separating from the Beta grains would be encountered by varying the composition and rate of cooling, although when the equilibrium relations called for separation of only a few percentage units of Alpha—particularly in a region of low temperature—difficulties of preparative and microscopic technique similar to those related in Professor Carpenter's first paper on Beta brass would arise; this, of course, had no bearing on the question as to whether Beta brass undergoes an eutectoid inversion or a polymorphic change at 470° C., but related solely to the separation of the Alpha phase in a finely lamellar state of division from the Beta constituent, or the suppression of such separation by undercooling.

The authors were gratified that Mr. Murray found much of practical value in the results contributed and regretted that, as he had pointed out, aside from the variation in chemical composition desired as a part of the investigation, there were certain other variations of composition which could only be regarded as unfortunate. It was perhaps appropriate to remark that, owing to the necessity of avoiding too great interference with the normal productive work of the mill, the authors were limited in the number of heats which could be taken for experimental work and only the more essential needs of the investigation could be cared for; for this reason, the No. II alloy was not duplicated in electro-copper nor was it corrected for a somewhat high lead-content. It was regrettable that two alloys of the compositions usually used for hot-rolling both in England and the United States, viz., approximately 60 per cent. copper, one containing arsenic and the other arsenic-free, could not have been included in the investigation. As pointed out, however, it was desired to secure compositions which would roll hot and which would at the same time possess exceptionally good cold-working properties; for this reason the copper-content was raised to above 62. To favour such properties, the authors were allowed

* *Journal of the Institute of Metals*, No 1, 1914, vol. xi. p 131.

to use comparatively pure spelter; the authors had had no experience with arsenic combined with high lead in brass; they would not, however, desire to convey the impression that American rolling-mill practice in a general sense differed from British practice by reason of either higher copper or lower lead. The authors thought that with the sole aid of the data in hand and incidental observations from actual practice, valuable though they might be, it would be useless to discuss the general question of the precise effect of different elements—arsenic, lead, etc.—in various combinations on the strength properties of Muntz metal; as Dr. Rosenhain had remarked in his discussion, the present paper “might be regarded as the beginning of a systematic research in regard to the influence of impurities on brass,” and it appeared justifiable to argue that arsenic in the present amounts and under the present conditions was rather beneficial than otherwise.

The authors agreed with Mr. Murray that on account of the earlier softening of the non-arsenical metal, it would anneal more rapidly at low temperatures than the arsenical metal, and a more prolonged annealing would be required to produce a given annealing effect in the latter case provided the annealing took place at a temperature below some $500^{\circ}\text{C}.$; at red heat this difference would be negligible. With regard to the value of micrographs at high magnification, most of the alloys had been examined with a $1/12''$ immersion objective, but no conclusions other than those stated in the paper had been reached.

It was believed that none of the testing results obtained could be construed to indicate any change of properties due to variable rates of cooling in passing the 470° transformation point; tests were made at 450° and 500° as a part of the general scheme of temperature selection in each of the several sets of experiments and certainly no marked change of properties occurred between these temperatures, as witnessed by the general continuity of all curves through this region.

The point raised by Mr. Murray that “in the preliminary annealing for one hour at $650^{\circ}\text{C}.$ followed by cooling at 2° per minute down to $300^{\circ}\text{C}.$, it might have been expected that the material would have developed, as was intended, its maximum ductility, but, unfortunately, it did not,” was well taken and served to illustrate the fact that the properties of these two-phase alloys were considerably dependent not only upon the cooling treatment after annealing, but also upon the period of annealing, even assuming that equilibrium-quantities of the two phases were developed in every case at the given annealing temperature. This was due to slow changes in the distribution (i.e. form, or arrangement) of the two constituents, according to the intensity of the annealing treatment. The authors had mentioned the particular change in this case in a footnote on p. 24, and had earlier alluded to Bengough and Hudson's experiments along this line. There was no question that the lower ductility of material annealed for a comparatively long period and cooled at a comparatively slow rate in the preliminary tests was due to a less favourable arrangement of the

Alpha and Beta constituents, although the actual comparisons between the tests reported would be influenced somewhat by the fact that preliminary tests were made on bars one-half inch thick, while later tests were made on strips 0.128 inch thick, with elongation measured in 2 inches in each case.

Mr. Murray's criticism of the authors' plan with respect to the rates of cooling chosen was to be answered by a statement on p. 33 of the paper, viz., "While linear rates of cooling do not prevail in ordinary annealing work, such rates afford the best basis of comparison and study." It appeared far easier to predict the result of any form of cooling which might be realized in practice from known results obtained at linear rates than from known results with variable rate of cooling—which could only be made to conform with one set of annealing conditions as realized in practice.

The authors were indebted to Mr. Murray for information relative to fracture tests. They had made no systematic examination of fractures.

Professor Turner's opinion that the paper should be judged as an attempt to deal with a practical problem with the aid of such knowledge of the scientific aspects of the question as could be brought to bear, was read with much gratification. There were many scientific aspects of such practical problems which could not be dwelt upon at length no matter how attractive they might seem to the investigator. For example, the authors had greatly desired to learn more about the constitutional relations involved in the treatment of this metal, in particular, the distribution of arsenic between the Alpha and Beta constituents.

The authors thought that Professor Turner's uncertainty as to whether the metal had fulfilled the expectations of tests in actual practice should be relieved by statements on page 20 of the paper, in which reference was made to the entire success of manufacturing operations on six cakes of the composition given. The metal did cup well and was reported excellent by the mill authorities.

There were constitutional reasons (dealt with rather fully in the paper, it was thought) for the fact that cold-worked alloys of this type first decreased in tenacity and increased in ductility on annealing with subsequent quenching and later (on annealing at higher temperatures) increased in tenacity and decreased in ductility.

The authors were quite in agreement with Dr. Rosenhain that the paper should be regarded as only the beginning of what might be considered a comprehensive research dealing with the effects of impurities on the properties of brass. They recognized the analogy between the effect of phosphorus in developing a banded structure in steel and that of arsenic in developing a banded structure in the Muntz metal alloys. They thought that this was due, as explained in the paper on page 43, to the influence of the added element on the diffusional process and not to an actual change in the solubility relations

between the Alpha and Beta constituents; in this connection, attempts had been made to compare the solubility relations in the two cases by planimetric measurements, but while no difference could be detected, this merely signifies, in view of the difficulties in the way of accurate quantitative work of this sort, that such differences are not considerable.

Dr. Rosenhain's remarks on the mutual effect of lead and arsenic and the possible influence of arsenic on the concentration of lead realized in the Beta phase served to emphasize the need of further work along constitutional lines. There seemed no end to work of this sort which would have to be done with every commercial product before the metallurgist could make accurate quality-comparisons.

Dr. Rosenhain's criticism that the temperatures actually obtained by placing the thermocouple in a V between two strips of brass were not really anything like within 5° of the true temperatures of the metal was founded upon a misconception of the authors' statements relative to the accuracy of the temperature measurements. They desired to convey the impression that with the simple apparatus used (a platinum, platinum-rhodium thermocouple in combination with a Siemens and Halske galvanometer of 400 ohms internal resistance) sufficient care was used to realize an accuracy within 5° C. Admittedly, there was some doubt as to the exact temperatures of the strips. In the case of experiments in which the metal was annealed in a furnace of quite flat temperature gradient at constant temperature and then quenched, it was believed that the actual temperatures of the strips were measured to an accuracy not far from 5° C. This conclusion was based upon many tests in which various regions of the tube and its contents were explored with the hot-junction. In the case of strips cooled with the furnace and then quenched, a considerable decrease in accuracy was admitted—perhaps from 5° to 30° C.

The authors felt that Dr. Rosenhain had gained an entirely false impression of the use of their testing results in drawing fine or unwarranted comparisons; they thought the results had been handled conservatively. In the first place, the printed record of Dr. Rosenhain's remarks gave the figure 0.015" as representative of the thinnest strips tested. According to the data on page 25 of the paper, all of the heat-treated specimens were tested at a thickness of 0.128" and the thinnest of the specimens tested after cold-rolling measured 0.073" in thickness, viz., 8 and 5 times as thick, respectively, as Dr. Rosenhain had supposed. The specimens were first machined to size, then heat-treated, and tested. The scale—chiefly zinc oxide—was readily detached, leaving clean surfaces from which consistently good gauge measurements were obtained. According to the authors' experiments in other work with specimens as thin as 0.015" satisfactory testing results could not be secured even with the use of as many as six specimens for an average, but with specimens of the present dimensions there seemed to be little doubt of the general value of the comparisons shown.

In alluding to the crossing of the upper curves of elongation in

Fig. 2, Dr. Rosenhain had taken one of the comparisons which would naturally be open to some doubt. In this case, the main contention was that Alloy No. III, which would possess higher elongation than Alloy No. I after comparable recrystallization, viz., above 500° C., possessed about the same elongation, or even lower elongation, than Alloy No. I at the low annealing temperature of 450° C., owing to retarded recrystallization. This point was supported by microscopic evidence. Admittedly, the question of the actual crossing of the curves was not positively decided by the data secured; annealing tests at lower temperatures would have been required to settle this point. Even with such data in hand, the accuracy of an eventual point of intersection was doubtless not much better than 50° C.

The authors believed that Dr. Rosenhain would concede the frequent necessity of compromising between certain refinements or elaborations which might be desirable, and a volume of work which could be done with little attention to detail, so that as a result a fair amount of ground could be covered with reasonable accuracy. The authors had tried to reach this middle ground working over a period of several months.

Professor Huntington's kind remarks were greatly appreciated. Something had already been written on the theme of broadening the work so as to deal more intimately with questions of constitution and the effect of impurities over a wider range. The quality of the metal from a manufacturing standpoint had also been touched upon.

Unfortunately, the authors had taken no samples and had made no examination of the cast slabs, so the question of segregation raised by Dr. Desch could not be treated directly. They thought that segregation in a limited sense, viz., segregation from centre to periphery of the original Beta crystals, could be predicted with certainty, not only in the case of arsenic, but in the case of almost any soluble impurity cast under these conditions. But there was no evidence in the rolled product of marked segregation such as was common in the case of lead and such as would give rise to considerable variation in the composition of the rolled product. A number of careful analyses had been made and the product was considered very uniform in its different parts.

Replying to Mr. F. Johnson's communication, the authors stated that they would gladly acknowledge the bearing of Mr. E. A. Lewis' experiments on the present subject. They had not made extensive citations of literature because the problem in hand dealt with a particular kind of copper and they had desired to deal chiefly with the question of comparisons as affecting this material and electrolytic copper, and not specifically with the effect of arsenic through any definite range of concentration or with other factors emphasized in other papers.

With reference to Table IV., in order to secure uniformity of testing results, the authors had considered a form of rolling which would yield test-strips of uniform thickness but variable degree of reduction by rolling. This had been given up, however, on account of practical

difficulties in the way of securing such a product. Mr. Johnson's suggestion that the values of elongation would have been more nearly comparable throughout the range of variable reduction by rolling if the test-length had been varied to bear a fixed relation to the area of section was, of course, admitted, but this procedure would not have affected the value of comparisons between the several kinds of material, which was the main consideration in mind.

Mr. Johnson's criticism of the authors' phraseology with reference to changes in the relative quantities of Alpha and Beta was wholly illogical unless it be established that of the two solubility curves bounding the Alpha + Beta field, only the curve constituting the boundary on the Beta side shows a change in solubility with the temperature. Every brass metallurgist was aware that the solubility of Beta in Alpha, as well as that of Alpha in Beta changed with the temperature; wherefore, the authors would correct Mr. Johnson's description of changes with falling temperature to read—Muntz metal immediately after solidification consisted entirely of Beta from which Alpha crystallized continuously on cooling and thereupon proceeded to dissolve Beta at a steadily decreasing rate as the temperature continued to fall. Although the separation of Alpha from Beta preponderated over the solution of Beta by Alpha on cooling through a low temperature range, this was by no means true on slow cooling through a high temperature range.

Finally, Mr. Johnson's conception of a "curious inconsistency" on the part of the authors in emphasizing the necessity for very slowly cooling the softer alloy (62.5 per cent. copper) after pointing out that the cold-rolled alloys "may be annealed at incipient red heat with little regard to the subsequent rate of cooling" when a high degree of ductility is to be met, was entirely at fault. Mr. Johnson quoted the authors' statement on page 64 correctly, but failed to note that slow cooling of the softer alloy (62.5 per cent. copper) was particularly recommended only after annealing treatment at temperatures above moderate red heat. In such case, the ductility was not recovered to a point comparable with that reached by simple annealing at low temperature (550° C.) unless very slow cooling was adopted.

THE ALLOTROPY OF SILVER *

By W. D. HELDERMAN, PH.D. (UNIVERSITY OF UTRECHT, HOLLAND).

INTRODUCTION.

HAVING been honoured by the Iron and Steel Institute with a Carnegie Research Fellowship, in order to carry out an investigation on the metastability of metals, the author intended to make iron the object of his researches. However, his experience proved the problem to be a very complicated one, even in the case of cadmium, copper, and other non-ferrous metals. He, therefore, changed his plan, choosing nickel as the metal to be experimented with. However it proved to be impossible, in consequence of the war, to get the pure metal in sufficient quantity. His choice, then, fell on silver, this being a metal which it was possible to obtain in a pure state and in any quantity wished for.

A record of the work done by the author on the metastability of the latter metal follows.

In view of the fact that the metal experimented upon is one that does not come within the purview of the Iron and Steel Institute, the latter Institute offered the present record—with the author's consent—to the Institute of Metals, by which it is now being published.

THE METASTABILITY OF SILVER.

I. HISTORICAL SURVEY.

In the first place a short survey of the earlier literature of the subject may be given here. This will show that there are many indications that silver is able to exist in more than one form. After having determined the density of different samples of pure silver, Matthiesen † expressed himself in the following way.

“ With silver it was not possible to get constant results although

* Read at the Autumn Meeting, London, September 20, 1916.

† *Poggendorf's Annalen*, vol. cx. (1860), p. 21.

it was melted under borax, sodium chloride and charcoal. The value $D^{13.2} = 10.486$ is the mean and thirteen different determinations varied between 10.424 and 10.511."

Such differences in a constant which can be so easily determined cannot be ascribed to experimental error, but must be attributed to changes in the metal itself.

THE WORK OF STAS.

Further evidence is given by the investigations of Stas, a part of whose life-work was devoted to researches on silver. Stas reached analogous results by means of his density determinations. Examples thereof are to be found in his "*Oeuvres Complètes*."

Some of them may be mentioned here:

The density of five pieces of silver (page 155) was found to be $D_4^0 = 10.4624$. These five pieces then were put into a press and after having been compressed the silver was hammered, so that finally there were obtained five pieces of 37 mm. diameter and 3 mm. thick; after which operations the density had become $D_4^0 = 10.5023$. After this treatment the pieces were heated to dull redness; they then showed very small bubbles, which were flattened by means of an agate bar, after which the density was determined again. The result was $D_4^0 = 10.4894$.

The pieces were hammered again, then cleaned; the density had increased to $D_4^0 = 10.5104$. Finally the silver was heated for $5\frac{1}{2}$ hours *in vacuo* to redness and allowed to cool *in vacuo*. After this operation the density had decreased to $D_4^0 = 10.4977$.

Other samples, obtained in different ways, gave widely differing values. Extreme values were 10.5537 and 9.8688.

Stas's explanation of these phenomena is in the present author's opinion not very plausible. According to this investigator, the differences are a result of occlusion of gases. It is known that silver is able to occlude oxygen and other gases, but this phenomenon does not explain the facts mentioned, as the density of silver, heated for some time *in vacuo*, decreased from 10.5104 to 10.4977. By heating the metal *in vacuo* gas only can be expelled, and this would increase the density of the metal; a decrease never can take place by this operation.

Looking for an explanation of these phenomena another view is to be taken, and in the first place, in the author's opinion, attention must be paid to the possible existence of different allotropic modifications.

THE WORK OF BERTHELOT.

In his paper on "Les Etats allotropiques de l'Argent" * Berthelot has taken into consideration the phenomena of allotropy. In connection with the results of his investigation on the behaviour of silver in presence of oxygen, † he determined the heat of solution of silver in mercury. Silver in various forms was used for this purpose :

1. Rolled silver in thin sheets.
2. Rolled silver in thin sheets, but heated for 20 hours in oxygen between 500° and 550°.
3. Needle formed crystals, obtained by electrolysis of a 10 per cent. silver nitrate solution.
4. Silver precipitated by means of a copper-plate from a dilute solution of silver nitrate, then washed and dried : (a) at room-temperature, (b) at 120°.
5. Ditto, but heated to dark redness.

The heat of solution (per gr. atom) of these different kinds of silver, was found to be :

1. + 2.03 Cal.
2. + 0.47 „
3. + 0.10 „
4. (a) 1.19 „
(b) 0.76 „
5. 0.08 „

Considering these values, Berthelot concludes that there must exist at least four allotropic forms of silver, the forms 3 and 5 being identical, at least changing into each other without any thermal effect. However, in the Author's opinion it is not necessary to postulate the existence of so many different forms, in order to explain the phenomena observed. Possibly the samples experimented with did not consist quantitatively of one form,

* *Annales de Chimie et de Physique* (7), vol. xxii. (1901), p. 307.

† *Ibid.*, p. 289.

but contained mixtures of α , β -silver in different quantities. The heat of solution found will thus be dependent on the quantities of α , β -silver which are present in the samples which have been used in the experiments.

Thirdly, there should be mentioned :

CAREY LEA'S INVESTIGATION.

In four papers* this investigator describes the properties of silver, obtained by reducing silver salts with either ferrous sulphate or dextrine and other organic materials. In this way he got silver preparations of different colour—grey, blue, gold-coloured, and so on—which he thought to be different allotropic forms of silver.

Summa summarum he distinguishes three forms : “allotropic silver ; an intermediate form ; and ordinary silver.” By different agents such as acids, pressure, heat, light, and so on, allotropic silver changes mostly via the “intermediate form” into “ordinary silver.”

The author further describes different properties of these forms of silver which we will not discuss here. However, his observation that the observed transformations of the allotropic silver are irreversible, is remarkable. Enantiotropic forms thus cannot play a rôle here. Evidently he worked with amorphous preparations, which also appears from his observation that some of his silver samples were soluble in water and alkaline solutions, which only is possible when colloid solutions are obtained.

Moreover, silver preparations obtained by reducing with organic substances are never pure. They always contain more or less of the organic substance. Carey Lea himself gives some analyses which prove this clearly, and the author's own analysis too, made on silver, obtained by the Böttger method (see page 90) prove this fact very clearly.

The very low density (8.5) of Carey Lea's allotropic silver is in the author's opinion to be attributed to the presence of these impurities.

Carey Lea's conclusions have been criticized by Meldola in a paper which is not accessible to the author ; consequently a discussion on this subject cannot be given here.

Analogous to the work of Carey Lea are :

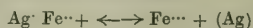
* *Philosophical Magazine* (5), vol. xxxi. (1891), pp. 238, 320, 497 ; vol. xxxii. p. 337.

THE EXPERIMENTS OF BLAKE.

According to colour, Blake* differentiates four allotropic forms of silver: white, blue, red and yellow silver. These forms are convertible into each other. For instance, blue and red silver are transformed into white silver by treatment with large quantities of strong mineral acids; blue silver by heating is changed into white. Light has the same influence; by pressure too this change can be made to occur. It seems to the author that these facts are not conclusive enough for us to accept the existence of four allotropic forms. Blake obtained the different modifications by precipitating silver in silver salts mostly with organic substances. That thereby he obtained crystallized forms only, is by no means necessary. Only in one single case does he describe crystalline white silver. It is possible that in this way amorphous preparations are generally obtained. Difference in colour may then be ascribed to difference in the size of the silver particles. Action of heat, acids, &c., would not only bring about change in the size of the particles, but this would give rise to transition into the crystalline form which may be accompanied by change in colour. Next we have to consider:

THE INVESTIGATIONS OF PISSARJFWSKY.

Pissarjfwsky also occupies himself with the allotropy of silver, when studying the equilibrium:



He failed in obtaining a constant value for this equilibrium, and from this he concluded that the common grey silver should be able to exist in at least two allotropic forms and that by the action of silver sulphate on ferrous sulphate two different silver forms or a mixture of both these forms should be precipitated. Determinations of the electromotive force between two samples of silver, used in powder form, gave no constant values. He also measured the heat effect of the reaction, mentioned above, under different circumstances. The values, found by him per gr. atom of silver, vary from 7.051 cal. to

* *Zeitschrift für anorganische Chemie*, vol. xxxvii. (1903), p. 243.

† *Ibid.* vol. lviii. (1908), p. 399.

14·523 cal. He not only investigated aqueous solutions, but also those containing a certain amount of glycerine, &c.

These differences may be explained by a difference in the degree of dissociation of the salts used in the solutions. However, it is not possible to explain in this way the total difference in the heats of reaction; there remain still one or more facts which might be explained by the presence of allotropic forms.

THE WORK OF LÜDTKE.

Lüdtke* prepared in different ways silver-mirrors on glass and other materials and chiefly investigated the electrical conductivity of these mirrors, but in some cases he also determined the E.M.F. of silver samples obtained in that way.

He stated that the electrical resistance of the mirrors decreased with time. Also by the influence of heat, light and the action of some chemicals, the conductivity was considerably increased. By means of some measurements of the E.M.F. he stated, that silver preparations, obtained by reduction in dilute acids, and most of the silver salt solutions showed against 'ordinary silver' an E.M.F. of $\pm 0\cdot1$ volt, the allotropic silver forming the positive electrode. When silver nitrate was used as an electrolyte, the E.M.F. was lower, and there was an inversion of the poles, the "allotropic silver" then forming the negative pole. Finally, he concludes that silver precipitated as a mirror in its original state corresponds entirely in its properties with solid colloidal silver.

Lüdtke's investigations are not of great importance. In the first place, Lüdtke, as he himself points out, very probably worked with amorphous silver, and as regards to the measurements of E.M.F. one can suppose that ordinary silver, as his standard electrode is called by him, probably was a crystalline preparation, such as is obtained by melting. From the author's experiments, however, it appears that in those samples at least three forms have been present and their E.M.F. consequently must be dependent on that form, the range of stability of which lies at the greatest distance from the temperature at which the investigation is carried out. Moreover, silver obtained by re-

* *Inauguralbliss. Greiswold, 1893.*

duction of silver salts is never chemically pure, as the following analysis made by the author shows.

Following Böttger's method a silver mirror of 35×40 sq. cm. was prepared. After washing it many times with distilled water, it was dried, after which the silver was scratched off by means of a bone spatula. In this manner 0.6807 gm. of silver was obtained, and dissolved in dilute nitric acid. There remained a residue and the solution was not clear. This residue was not formed by silver chloride; in the first place all chemicals used were free from chlorine and, secondly, the precipitate was not soluble in ammonia. The solution was filtered off, after which the silver was precipitated by means of hydrochloric acid. Then the silver chloride was filtered off, washed with distilled water, and dissolved in a warm solution of potassium cyanide. Finally, the solution obtained thus was electrolyzed in a platinum dish, with a current of 0.2 amp. The silver thus formed had a weight of 0.6873 gm., the original mirror containing thus 93.62 per cent. of pure silver. An analysis carried out with another mirror, which had been prepared using other materials, showed the percentage of silver to be 94.3.

THE EXPERIMENTS OF JÄNECKE.

These contain some contradictory results, which may be mentioned here. Jänecke* compresses silver (as well as other metals, salts, &c.) in a steel cylinder, heating them electrically by means of a metal wire wrapped round the cylinder. Plotting the pressures as ordinates and the time as abscissae, the breaks of the curves obtained correspond to transition temperatures.

In the first place, Jänecke forgets that transition temperatures depend upon pressure and that as the pressures used are as high as 20,000 kg. per sq. cm., a considerable influence on the transition point may be expected.

In the second place, the cylinder used was not closed; at the lower end there is an opening. Consequently all experiments are carried out under unequal pressure. Having in mind the complexity of the phenomena under these circumstances,

* *Zeitschrift für physikalische Chemie*, vol. xcix. (1915), p. 257.

Jänecke's results are dubious. Finally, the corrections of pressure to be applied with a view to allowing for the leakages occurring in his apparatus are so great, that they often exceed the differences in pressure to be measured. One example may explain the unreliability of these experiments.

For the determination of the transition point grey tin \longleftrightarrow white tin, Jänecke cools his apparatus, filled with tin, below 0° , and then warms it up slowly whilst the metal is under pressure. He now observes, by heating, a decrease of pressure, and from the pressure values found he concludes that there is a transition point near 23° . The following points here are to be considered.

1. That by simply cooling to 0° , during a very short time, white tin does not change at once into grey tin. The investigations concerning the allotropy of metals have shown quite clearly that such transformations go on very slowly.

2. Moreover, Jänecke recorded a decrease of pressure below the transition point. The only possible change there, supposing that grey tin be formed, would be that white tin becomes transformed into grey; this is accompanied by a volume increase, and consequently therewith an increase of pressure. A decrease of pressure is impossible; leakage must have caused the phenomena.

II. EXPERIMENTAL SECTION.

MEASUREMENTS WITH THE PYCNOMETER.

The Materials Used.

The silver experimented with was the purest mint-silver, kindly lent for this object by Dr. Hoitsema, Master of the Royal Mint, to whom the author expresses his heartiest thanks.

The silver nitrate used for the different solutions was a preparation "pro analysi"; the sulphate of potassium the purest preparation from Kahlbaum of Berlin.

The Determinations of Density.

In order to get insight into the possible allotropic forms of silver and their limits of stability, silver first was subjected to an investigation with the pycnometer. For this purpose two different

forms of pycnometer were used—in the first place the instrument described by Johnston and Adams* as shown in Fig. 1. Besides the precautions taken by these authors the pycnometer was always, before weighing, plunged into the water of the thermostat, and afterwards dried with a handkerchief. In this way the glass was in the same condition as at the following

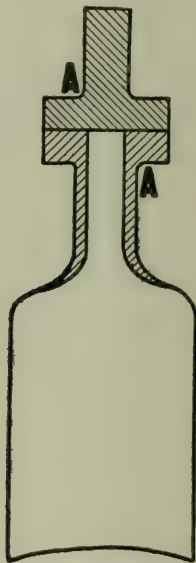


FIG. 1.

weighings, when the pycnometer had been for a long time in the water of the thermostat. The capacity of the pycnometer was about 25 c.c. Generally, however, use was made of pycnometers with ground capillary stoppers. The stoppers were about 2.5 cm. long and were very carefully ground in. On the capillary (length ± 5 cm., lumen 0.7 mm.) an index was scratched. The determinations were carried out in the following way:

The weight of the pycnometer having been determined, the flask was filled with silver and weighed again. Then a certain quantity of the liquid (at first toluene; afterwards air-free distilled water) was added, so that the metal was covered by the liquid. In order to remove the air, the pycnometer was then

* *Journal of the American Chemical Society*, vol. xxxvii. (1912), p. 563.

connected for some time with the water pump; finally the whole was filled with liquid and placed into the thermostat which had a temperature of 25.0° , remaining constant within 0.01° . All densities refer to water of 4° as a unit, and are reduced to vacuo.

One of the determinations of the density of toluene, which sometimes was used as a liquid in the pycnometer, may serve as an example.

The toluene was dried over sodium for several days and then distilled from it. Boiling point 110.2° – 110.6° . All density determinations were repeated twice, using two different pycnometers.

Determination of the Density of Toluene at 25.0° .

Weight of the pycnometer + water	= 47.7309 gr.
" " " " empty	= 24.2148 "
Weight of the water	= 23.5161 "
" " pycnometer + toluene	= 44.4490 "
" " " " empty	= 24.2148 "
Weight of the toluene	= 20.2342 "
$D_4^{25} = \frac{20.2342}{23.5161}$	$(0.9971 - 0.0012) + 0.0012 = 0.8581.$

0.9971 is the density of water at 25.0° , the density at 4° taken as unit.

A second determination, using another pycnometer, gave the same value, $D_4^{25} = 0.8581$.

Of course, the agreement of two experiments with silver as a solid was not so satisfactory, although the greatest differences between two determinations never exceeded three units in the third decimal place. The density of the silver from the Mint was next determined. This silver was rolled, and before use it was cut into small pieces which were washed with alcohol and ether and dried at $\pm 50^{\circ}$. After this, a part of the silver was taken (± 77 gm.) and its density determined. Two separate measurements gave:

$$D_4^{25} = 10.4879 \text{ and } 10.4868 \text{ respectively.}$$

This silver will be referred to subsequently as S_1 . After this experiment S_1 was taken out of the pycnometer and heated for 72 hours at 100° in a 10 per cent. solution of silver nitrate. The object of this was to obtain, if possible, by heating the silver at a given temperature, an allotropic change, an electrolyte acceler-

ating the reaction, as appears from the investigations on the allotropy of copper, lead, cadmium and other metals, which the author had the honour of making in collaboration with Prof. Ernst Cohen. After heating, the silver had become black. Treating it with dilute nitric acid, the black colour disappeared and it became bright as before. Next S_1 was washed with distilled water, alcohol and ether and dried at $\pm 100^\circ$, after which the density was determined. The values found were:

$$D_4^{25} = 10.4887 \text{ and } 10.4927 \text{ respectively.}$$

As the blackness of the silver was probably a consequence of reduction of the silver nitrate, the solution with which the silver had been heated was examined for the presence of nitrite, and in fact it appeared to contain this. Consequently no silver nitrate was further used, but a 10 per cent. solution of potassium sulphate was employed.

That the density of S_1 had not been altered by heating, might be explained by assuming that the form in which the silver was used was very unsuitable for transformation: no fine powder being present. The author's experiments on the allotropy of cadmium,* as a collaborator of Prof. Cohen, showed that cadmium, used in the same form, could be heated a hundred degrees above its transition point without any transition taking place.

For this reason the silver was melted and poured out into cylinders made of asbestos paper. As soon as the metal had solidified, the cylinders were chilled in water and turned into thin shavings on a lathe. The density of this material (S_2) was then determined. The following values were found in two determinations with different pycnometers:

$$D_4^{25} = 10.4744 \text{ and } 10.4774 \text{ respectively.}$$

S_2 was now heated for 96 hours at 100° in contact with a 10 per cent. solution of potassium sulphate, then washed with dilute nitric acid, distilled water, alcohol and ether and dried at $\pm 80^\circ$. A redetermination of the density gave the following result: $D_4^{25} = 10.4790$. In a second determination, S_2 having been washed with alcohol and ether and dried at $\pm 80^\circ$, gave the value $D_4^{25} = 10.4910$. There is no agreement between these two values. Experimental error being excluded, it must be assumed that some-

* *Zeitschrift für physikalische Chemie*, vol. lxxxvii. (1914), p. 409.

thing happened to the material between the determinations; later we shall see that this really has been the case.

Immediately after the experiments mentioned above, S_2 was put again into a solution of potassium sulphate and heated for 144 hours at 100° . The silver had now become somewhat violet in colour, but after having been washed with a dilute solution of potassium cyanide this colour disappeared. After further washing with distilled water, alcohol and ether and drying at about 80° , the density of S_2 was determined. The result was $D_4^{25} = 10.4812$. A second experiment, carried out after the material had been dried at $\pm 80^\circ$, gave a density $D_4^{25} = 10.4978$. Again these two values do not agree.

The author then heated S_2 in a solution of potassium sulphate for 192 hours at 100° , and after washing the material in the usual way, the density was determined again.

Previously use was always made of the pycnometers as described by Johnston and Adams, now pycnometers with capillary stoppers were used. Air-free distilled water was used as liquid.

It was observed that, whilst the pycnometer was standing in the thermostat at 25° , the water meniscus in the pycnometer was continually falling at a constant temperature. That leaks are out of question was shown by an experiment, during which the pycnometer, only filled with water, was hanging in the thermostat. A fall of the meniscus did not take place then. Thus we may conclude that the density of the metal increased at 25° during the determination. The density found was $D_4^{25} = 10.3630$. A second experiment, after the sample had been dried at $\pm 80^\circ$, gave $D_4^{25} = 10.3866$.

These facts explain how it is that in two determinations of density of the same sample, corresponding results could never be obtained. At 25° it appeared from the fall of the meniscus that the density of the metal increased at that temperature. Consequently two determinations never can provide the same values of the density, and the second experiment always must give the higher density; this was found in the determinations mentioned above.

Next S_2 was put into a thermostat at 25° , in contact with a solution of potassium sulphate, and kept at this temperature for 72 hours. Then the material was washed and dried *in vacuo* at

room temperature over sulphuric acid, because drying it at a higher temperature probably would cause transformation of the metal.

The density was now $D_4^{25} = 10.3932$ and 10.3963 . Between these determinations S_2 was dried *in vacuo*. Whilst the pycnometer was in the thermostat, the meniscus fell again.

The pycnometer was now left in the thermostat till the following day, then water was added and the density determined again.

It was found to be $D_4^{25} = 10.4830$. Keeping the metal (S_2) 120 hours in the pycnometer at 25° , the density had not changed. Consequently at 100° the density of silver decreased; at 25° , on the contrary, an increase took place. According to these experiments a transition point between 25° and 100° might be expected.

To determine this with greater certainty, before carrying out an experiment with the dilatometer, other samples of silver were investigated in the same way, as described above. First of all a quantity of *electrolytic silver* was examined. From the investigations on cadmium, tin, &c., it appeared that metals precipitated electrolytically are metastable. Here then the same phenomena might be expected. Moreover, by electrolysis of a solution of silver nitrate, very fine crystals, which are very suitable for transformation, are obtained without inclusions of other matter.

The preparation, then, was made in the following way:

A 10 per cent. solution of silver nitrate was poured into a platinum dish, which served as a cathode; a disc of pure mint silver wrapped up in filter paper being used as an anode. The platinum dish was covered with a glass plate and black paper. The current from two storage cells was passed through the cell (200 m.a.). In this way 77 gm. of silver (E_1) were precipitated.

This preparation, after having been washed with distilled water, till the silver reaction in the water had disappeared, was dried *in vacuo* over sulphuric acid. Then the density was determined and found to be $D_4^{25} = 10.3062$ and 10.3554 . Here, too, there is no agreement between both values, in accordance with the fact that the water meniscus fell during the experiment. The second experiment again gave the highest density.

The silver in the pycnometer was left in the thermostat at

25° over night. The next day water was added and the density was determined again. It had increased to $D_4^{25} = 10.4360$.

Then E_1 was put into a solution of potassium sulphate and heated at 100° for 120 hours. After having been washed with a solution of potassium cyanide, distilled water, alcohol and ether, and after drying *in vacuo*, the density was found to be $D_4^{25} = 10.3128$ and 10.3498. During the experiment the metal shrank again in the pycnometer. The silver was left in the pycnometer at 25° till the following day; then the density had increased to $D_4^{25} = 10.4292$.

In order to get the opposite transition and to prove the reversibility of the change more clearly, E_1 was heated at 100° in a solution of potassium sulphate for 120 hours. After the usual washing and drying the density of the metal was determined. Using two pycnometers $D_4^{25} = 10.3257$ and 10.3263 were found. Between both determinations the silver had been dried at 100°.

Here, as with S_2 , treatment with a solution of potassium sulphate at 100° produced a decrease of the density, treatment at 25° on the contrary causing an increase of density.

A new series of experiments was carried out on silver that had been used for the investigation with the dilatometer (vide p. 105).

The dilatometer was opened, the silver washed with ether in order to remove the paraffin oil that had been used as a liquid in the dilatometer. Then the metal was dried at 50°. This temperature was lower than the lowest temperature at which the dilatometer had been exposed.

The density of a part of this material (S_3) was determined and found to be $D_4^{25} = 9.4698$.

Although this value is exceptionally low, it is not so remarkable. Stas, for instance, found a density $D_4^0 = 9.8688$. After this determination, S_3 was washed with alcohol and ether and heated at 50° for two hours. The density then had increased to $D_4^{25} = 10.0759$. Now S_3 immediately was put into a solution of potassium sulphate at 50° and left at this temperature for 24 hours. After having been washed and dried at 50°, the density of the metal was determined. The result was $D_4^{25} = 10.3043$. The silver shrank in the pycnometer considerably, so that, after two hours, the density had increased to $D_4^{25} = 10.4647$.

Again S_3 was heated at 50° for 48 hours. Two determinations of the density gave as result $D_4^{25} = 10.4712$ and 10.4743 .

In order to produce a stronger increase in the density of the silver, it was heated next for 192 hours in a solution of potassium sulphate at 50° ; the density had then increased to $D_4^{25} = 10.4887$.

On page 96 the supposition has already been made that electrolytic silver probably would be in a metastable condition. Thus according to the preceding experiment, it must have a low density. To demonstrate this, S_3 ($D_4^{25} = 10.4887$) was wrapped in parchment and a platinum wire was put into the metal which was used as an anode. As a cathode a platinum dish was used, the contents of which were 350 c.c., whilst a 10 per cent. solution of silver nitrate was used as an electrolyte. The density of the silver, precipitated during this electrolysis, was determined, the metal having been washed and dried before. The author found $D_4^{25} = 10.4547$.

During the determination the density of the metal changed, as was proved by the falling of the water meniscus in the pycnometer. Stabilization must thus also have taken place in the solution of silver nitrate. Had this not been the case, the density would have been considerably lower. The silver was left for 24 hours in the pycnometer; the density then had increased to $D_4^{25} = 10.4729$.

In order to determine whether the material in the dilatometer had become homogeneous a fresh quantity (S_4) was taken out of the original mass. If this preparation too had a density $D_4^{25} = 9.4698$, just as S_3 , it would be very likely that there had been obtained one of the varieties of silver in a pure condition. However, this appeared not to be the case, the sample having a density of $D_4^{25} = 9.8201$. Certainly this value also is very low, but it differs from S_3 ($D_4^{25} = 9.4698$) too considerably. Thus the material was not homogeneous.

Like the silver samples already described S_4 changed itself during the determination into a form of greater density, so that, after having been for 24 hours in the pycnometer at 25° , the density had increased to $D_4^{25} = 10.0962$.

Contrary to S_3 , which was heated at 50° in a solution of potassium sulphate, S_4 was now heated in the same solution at 25° . The

object was to look for a temperature as favourable as possible for stabilization, in order to obtain in that way pure *a* silver (the stable form at room temperature). After the metal had been treated in that way for 24 hours, the density was determined. For two determinations, carried out with two different pycnometers, the values $D_1^{25} = 10.3687$ and 10.3689 were obtained. With the object of carrying still further the stabilization, the same treatment was applied next for 48 hours. The density then had increased to 10.4462 , this figure being the result of two determinations which gave the same values.

During the following days S_1 was heated continually at 25° in contact with a solution of potassium sulphate, from time to time the density of the metal being taken, in order to determine whether a final value had been reached. In this way the following figures were found:

After	5 × 24 hours	.	.	.	.	.	$D_1^{25} = 10.4774.$
„	6 × 24	„	.	.	.	.	„ 10.4867.
„	15 × 24	„	.	.	.	.	„ 10.4861.
„	28 × 24	„	.	.	.	.	„ 10.4870.

In the last three determinations no further noticeable change in the density had taken place. In order to decide whether the metal had become entirely homogeneous, it was divided into two parts. Of each part the density was determined. As density of both samples the author found:

$$D_4^{25} = 10.4889 \text{ and } D_1^{25} = 10.4884.$$

S_4 appeared to have become homogeneous and the author got the impression that he had obtained a material entirely stable at 25° . To investigate this point galvanic cells were constructed, according to the scheme:

Part of S_4	|	solution of silver nitrate (10 %)	|	part of S_4	(I)
Part of S_4	|	solution of silver nitrate (10 %)	|	silver electrolytically deposited	(II)
Silver electrolytically deposited	|	solution of silver nitrate (10 %)	|	silver electrolytically deposited	(III)

If really S_1 was the stable form at 25° , it would show an E.M.F. against electrolytically deposited silver. The measurements were carried out at 25° by the Poggendorff compensation method. The resistances used had been checked by the Physikalisch-Technische Reichsanstalt at Charlottenburg-Berlin. The same was the case with the thermometers used. Two standard elements (Weston) were put into a thermostat which was kept at

25°. As a zero instrument there was used a Desprez-d'Arsonval galvanometer. It was mounted on a vibration free suspension (Julius). The readings were made by means of a telescope and scale; 0.02 millivolt could easily be measured.

The following E.M.F. were found :

E.M.F. cell (I) 0.0000748 volt.

„ „ (II) 0.0000187 „

„ „ (III) 0.0000654 „

Practically speaking, the E.M.F.s between the different samples were 0. S_4 thus was not entirely stable, though probably there was but a very small proportion of the metastable form. This form, however, always determines the potential, as its solution tension is greater than that of all other. In that way it appeared impossible to obtain a material entirely in the stable form.

EXPERIMENTS AT HIGHER TEMPERATURES.

After the experiments mentioned above, experiments were carried out in order to determine the behaviour of silver at higher temperatures. With this object S_4 ($D_4^{25} = 10.488$) was heated at about 400° for 4 hours in a quartz crucible, after which it was quenched in cold oil. A density determination subsequently carried out gave the value $D_4^{25} = 10.4879$.

Practically the density had thus not changed. The same treatment was then repeated, but for a longer time—22 hours. A determination with the pycnometer gave the value $D_4^{25} = 10.4869$. This behaviour was reminiscent of that of the allotropic forms of silicon dioxide which were investigated by Fenner.*

Fenner found that the different allotropic forms of silicon dioxide can be heated for a very long time at a high temperature, far above their limits of stability, without any transformation; and if some changes in the material did take place, they always were very incomplete. The addition of melted salts—in the case of SiO_2 , Na_2WO_4 —accelerated the transition so that it became complete after some time. Thinking the case of silver an analogous one, S_4 was heated for 72 hours at about 400° in contact with a melted mixture of potassium and sodium nitrates, mixed in equi-molecular

* *Zeitschrift für anorganische Chemie*, vol. lxxv. (1914), p. 133.

quantities, then chilled in cold water. The mixture of salts dissolved very quickly in water, so that the silver could be obtained in a pure state without any difficulty. After having been washed with alcohol and ether, it was dried at 100° , then the density was determined— $D_4^{25} = 10.21608$. Here then, analogous with the case of silicon dioxide, the melted salt acted as an accelerator of the transition. Yet complete transition did not take place, as was proved by the high density.

EXPERIMENTS WITH ELECTROLYTICALLY DEPOSITED SILVER.

As the transitions of solid substances are generally highly accelerated by using them in a finely divided state, the author carried out a series of experiments with silver deposited electrolytically.

A sample was prepared, using a current of about 1.5 amp. A solution of silver nitrate (10 per cent.) was taken as an electrolyte. A disc of pure mint-silver, wrapped up in filter paper, formed the anode, a platinum disc being employed as a cathode.

After preparation the metal remained for 4 days at room temperature in the silver nitrate. Then the metal was washed with water (till the silver reaction in the water had disappeared) with alcohol and ether, after which it was dried and the density determined. This was found to be $D_4^{25} = 10.1487$. After the silver had remained for 24 hours in the pycnometer at 25° , the density had increased to $D_4^{25} = 10.1822$, after the same treatment for 48 hours to $D_4^{25} = 10.4513$. The metal S_7 (analogous to S_4) was now put into a solution of potassium sulphate at 25° and left for 17 days at this temperature. Then the density was $D_4^{25} = 10.4881$. Next S_7 was heated in a quartz crucible for 48 hours at about 400° , chilled in cold water and dried at 100° ; then the density was determined; it appeared to have decreased to 10.3785.

Without using melted sodium and potassium nitrates a transition had taken place, contrary to S_4 , but very fine material had been used.

In order again to test if at 25° an increase of the density always arises, whatever may be the treatment that the metal has undergone, S_7 was put into a solution of potassium sulphate,

remaining therein for 48 hours at 25° , after which treatment the density was determined anew. It had increased to $D_4^{25} = 10.3882$.

S_7 was now dried, and heated again at about 400° for 4 days and nights, but now in contact with melted sodium and potassium nitrates. After chilling in cold water, washing and drying at about 80° , the density had decreased to $D_4^{25} = 10.2645$.

EXPERIMENTS AT A LOW TEMPERATURE.

As some preliminary experiments had shown that silver deposited electrolytically always had different but low densities and as the investigations of Richards and Hulett prove that these preparations do not contain any inclusions (which would lower the density), a series of experiments was carried out in order to see if it would be possible to reach a final value.

If the deposition of the metal takes place at ordinary temperatures it would be possible that the metal, originally deposited in a metastable condition, might be stabilized with great velocity, as it is continually in contact with the solution from which it is generated. By lowering the temperature at which the electrolysis is going on, the velocity of stabilization would be decreased and in this way it might be possible to get a definite metastable condition of the metal.

The following method therefore was adopted: The metal was deposited at about -20° C. As an aqueous solution of silver nitrate cannot be used at this temperature a solution in 50 per cent. alcohol was taken, containing ± 6 per cent. silver nitrate. At 20° this mixture remained homogeneous. The temperature was regulated by throwing pieces of solid carbonic acid into an alcohol bath, into which an isolated platinum disc was placed and upon which the silver was deposited. In order to prove that silver deposited from a 6 per cent. silver nitrate solution in 50 per cent. alcohol at -20° did not contain inclusions, two coulometers were inserted in the circuits: one, filled with an aqueous solution of silver nitrate (10 per cent.), at room temperature, the other, containing a 6 per cent. solution in 50 per cent. alcohol, at -20° .

After the current had passed through for some time, the

coulometers were washed with distilled water, alcohol and ether, dried and weighed. The result was :

For coulometer I 4.3838 gr. of silver.

 " " II 4.3871 " "

In both, the same quantity of silver thus had been deposited.

Now a quantity of silver was deposited in the manner above mentioned at -20° , and the density of this material determined— $D_4^{25} = 10.3989$. In this case also the author obtained an intermediate value, and the process of stabilization has thus not been prevented at this low temperature.

The general result of all measurements carried out was that the density of different preparations, made in various ways, always decreased at 100° , or at a higher temperature, and after treatment at 25° or 50° increased.

From this, the conclusion may be drawn that there must be a transition point between 50° and 100° . A final density determination could not be obtained, so that, as with cadmium, copper, &c., no pure forms could be obtained. Always a mixture of (at least) two forms appeared to be present. In order to determine the transition point as accurately as possible, there was carried out

An Investigation with the Dilatometer.

Before describing the actual dilatometric investigation, some remarks may be made with regard to the apparatus used and the method followed which, in certain respects, differ from those followed hitherto. In order to obtain a greater precision than that obtained until now for the determination of a transition point, the following precautions may be adopted :

(1) As great a quantity of material as possible should be taken, and the capillary tube have a small bore.

(2) Take as small a quantity of liquid as possible, which lessens the thermometrical action of the instrument. If there is not material enough to fill up the dilatometer entirely, the remaining space may be filled up with a number of glass beads.

(3) The temperature of the experiment should be kept as constant as possible. This may be done by using a thermostat.

such as that described below, this one enabling the author to keep the temperature constant within 0.003° till about 130° . The

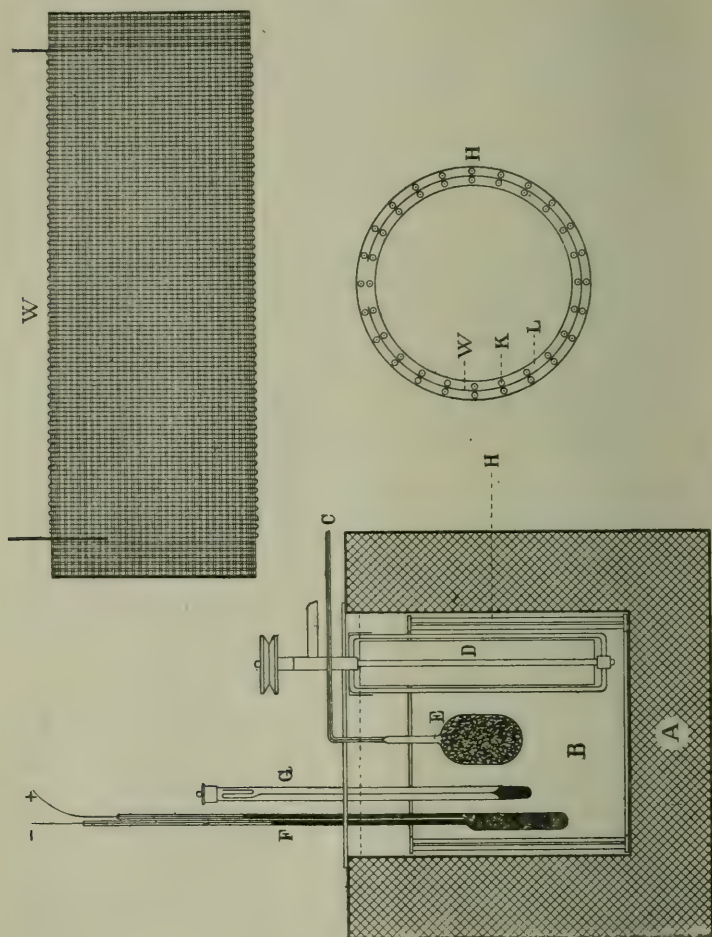


FIG. 2.

dilatometer E (Fig. 2), which contains about 300 gr. of silver, has a capillary (bore of the capillary tube 1 mm.) bent down horizontally. A porcelain scale, divided into millimetres, is attached to the capillary. Paraffin oil which has been previously heated at about 200° for some hours in contact with some silver powder may be used as a liquid. To remove air-bubbles, each dilato-

meter is evacuated for a considerable time by means of a Gaede vacuum pump. After the dilatometer has thus been prepared, it is placed into a thermostat which may be heated electrically.

B is a copper cylinder of 30 mm. diameter and 35 cm. high surrounded by a layer of slag wool 11 cm. thick. The outside is made of zinc. B is filled up with mineral oil. If it is necessary to work at higher temperatures, valvoline cylinder oil may be used up to about 200° ; at this temperature it produces very little vapour. The whole is covered by a cover of "eternite," provided with holes which allow them to pass the capillary tube of the dilatometer, the thermoregulator F, a Beckmann thermometer G, and a stirrer D, driven by a hot-air motor. On the inside B, at about 2 cm. distance, there is a wire-net W of nickel, fastened to an apparatus H, provided with glass rods K. This wire is connected with the electric central station of the town (222 volts, strength of the current 1.5 amp.).

The regulating of the temperature takes place by means of 3 relays, just as described in *Piezochemische Studien VIII.** However, care should be taken to avoid contact of platinum with platinum, as there may occur in this way welding of the platinum wires. Contacts always should be made of platinum-iridium, which cannot be welded. By these precautions it is possible to keep up a constant temperature within 0.005.

The following experiments were next carried out: A dilatometer was filled with 750 grams of silver that had been previously melted and poured out into an asbestos cylinder. As soon as the metal had solidified, the cylinder was chilled in water. Then the metal was turned into fine shavings on a lathe and these were used without any previous treatment with an electrolyte. After a capillary tube had been fused on to the dilatometer, it was connected with a Gaede vacuum pump. Between the capillary and the pump a kind of pipette was attached, filled with paraffin oil. As soon as the air was driven out, the liquid was allowed to enter. This pumping was repeated several times, till all the air was driven out. Then the apparatus was ready for use and was put into the thermostat, described above. Before each first reading an hour was allowed to elapse; at the end of that time it was certain that the dilatometer had reached the temperature of the

* *Zeitschrift für physikalische Chemie*, vol. lxxviii. (1911), p. 299.

bath. With the first filling of the dilatometer the following results were obtained, which are set out in Table I.:

TABLE I.

Temperature Deg. C.	Duration of Heating in Hours.	Total Rise of the Oil in Mm.	Rise of the Oil per Hour in Mm.
50.1	4	- 1650	- 412½
78.6	24	+ 4	+ ⅙
80.7	21	+ 45	+ 2.1
85.3	9½	+ 200	21.
76.1	11½	- 255	- 22
78.0	12½	0	0

This table shows that the silver had a transition point at 78°.

In order to determine whether anything in the previous thermal history of the metal had an influence on the temperature of transition the metal was heated in the dilatometer for 48 hours at 90°, i.e. above its transition point. Then the temperature was lowered, oil added and a further reading taken.

These results are set out in Table II.

TABLE II.

Temperature Deg. C.	Duration of Heating in Hours.	Total Rise of the Oil in Mm.	Rise of the Oil per Hour in Mm.
76.1	1½	- 63	- 42
78.0	20	- 8	- 0.4
79.0	24	+ 7	+ 0.29

From these values we may conclude that there exists a transition point at 78.6°. Consequently, heating of the material at 90° for 48 hours practically had no influence on the temperature of transition. However, it seemed not impossible that the change in the thermal history, above mentioned, was too small to cause a perceptible change of the temperature of transition. Therefore the metal was melted again, chilled in cold water and turned into fine shavings on a lathe. The dilatometer was filled with this material; and for the rest the author proceeded in the manner

described on page 105. With this material the following readings were made :

TABLE III.

Temperature Deg. C.	Duration of Heating in Hours.	Total Rise of the Oil in Mm.	Rise of the Oil per Hour in Mm.
70.0	6	- 24	- 4
84.4	2	+ 20	+ 10
77.0	8	+ 6	+ 0.75

From these results it must be concluded that there exists a transition point at 76°. Melting the silver and chilling it afterwards caused a change of 2°.

This behaviour is reminiscent of that of cadmium,* copper,† lead and some other metals, and the phenomenon can be explained in the same way. Agreeing that there are (at least) three forms of silver, the fact is very clear that, depending on the quantity which is present of the third form, the temperature of transition will be found higher or lower.

It is not remarkable that, experimenting with the pycnometer, this fact had not been observed, since the quantities of the metal used to determine the density are too small to show these little differences. From the experiments with the pycnometer and the dilatometer we finally may conclude that :

1. Silver has a transition point at about 77°.
2. Pure silver consists of (at least) three allotropic (enantiotropic) forms.
3. All objects made of silver are in a metastable condition as a result of the retardation in the transition of the altered form.
4. All physical constants of silver (excepting the atomic weight) refer to indefinite mixtures of the different allotropic forms. New experiments are wanted to obtain constants for the different forms of silver in a pure state.

* *Zeitschrift für physikalische Chemie*, vol. lxxxix. (1915), p. 493

† *Ibid.*, p. 638.

DISCUSSION

Sir THOMAS ROSE, D.Sc., Member of Council, in introducing the paper in the Author's absence, said that it was generally admitted that the phenomena referred to at the bottom of page 85 were not peculiar to silver, namely, that when it was heated it became less dense and when it was hammered it became more dense. It was generally agreed that this was due to the expansion on heating of the bubbles of gas taken up by the metal when it was cast and to the compression of the gas cavities when the metal was hammered or rolled. Silver was peculiarly liable to contain gas bubbles when it was cast. The Author evidently had had to struggle against the difficulty of getting consistent results, but in general they showed that when heated at 100° in potassium sulphate the silver decreased in density and when kept at 25° , i.e. at the ordinary temperature, it increased in density.

In the Author's conclusions it was stated that three varieties of silver had been found to exist. There was some evidence as to two varieties of silver but he could not find any evidence in the paper as to the third variety.

The Author did not claim that he had prepared any one of the varieties in a pure state, and consequently it would be premature to try to assign definite constants to them. It seemed possible that a satisfactory explanation could be given of the phenomena observed by the author without assuming the existence of more than one form of silver.

Dr. W. ROSENHAIN, F.R.S., Member of Council, in opening the discussion, said that he had a little difficulty in considering the paper quite seriously. He had read with considerable interest a whole series of papers on the alleged allotropy of many metals, principally emanating from the Utrecht Laboratory; and, with every respect and reverence for the scientific attainments of the workers there, particularly Professor Cohen, he had so far failed to understand how it was possible to base upon the data obtained by those various workers anything like the sweeping conclusions which they put forward; and he thought the present paper was a striking example of that kind of thing. First of all, the whole of the evidence was based apparently upon one single property—change of volume or density. Even if there were constant marked changes of density, it was a very open question whether it would be necessary to ascribe them to allotropic transformations. With regard to the actual experimental facts quoted in the paper, he thought there were certain fairly obvious explanations which put aside altogether any necessity for invoking two or more forms of allotropic silver. First of all the material which the Author used—and he believed similar material had been used by Professor Cohen

and his fellow-workers in the cases of copper and cadmium referred to—were turnings. Turnings were extremely cold-worked material which had been actually strained beyond the breaking point, where it had been cut away, and consequently if the views which Sir George Beilby had put forward, and which were very widely accepted nowadays, were correct, that such severe strains produced a large amount of amorphous material, an explanation was at once afforded of a large number of the observations. The exact temperature at which amorphous materials began to undergo transformation was, he believed, quite low, and not only that, but it was quite possible that minute changes of density might go on at quite ordinary temperatures to a slight extent in severely strained metal. There was the temporary mobility of the amorphous material when first produced, the changes which it underwent when settling down into its vitreous condition; a whole series of complicated changes went on in the metal. The first point he desired to make was that before serious attention could be paid to the data as indicating allotropy in silver, other than a change from the amorphous to the crystalline condition, the experiments would have to be carried out with silver which had been annealed at a high temperature in such a way as to eliminate all amorphous matter as far as possible and to avoid all subsequent straining.

Another set of facts, however, required consideration. One of the principal observations upon which the Author based his views was the steady change of density which apparently occurred when silver turnings were kept in a pycnometer at the ordinary temperature of 20° to 25° C. He thought the explanation which the Author suggested, that the silver was undergoing a slow allotropic change, was almost the least probable that could be advanced. The actual facts were pretty plain when it was remembered that metals were not entirely impervious to water. It was pretty well known that it was possible to force water under high pressure through many apparently solid metals. In that connection he would like to quote an investigation made at the National Physical Laboratory by his colleague, Mr. Sears, with regard to standard weights. His colleague had found that weights made of solid hammered metal actually absorbed an appreciable amount of water, so much as to render them inconstant for weighings of the highest accuracy. A piece of metal which was intended for use as an international comparison standard, consisting he believed of equal parts of copper and nickel, which had been hammered and carefully machined and polished, was found to absorb an appreciable amount of water when moistened. When that occurred with such a metal he thought it was not too much to say the probability was that the change in the pycnometer observed by the Author was purely and simply a question of the absorption or adsorption of water by the silver during prolonged exposure to it. Of course when the metal was heated up again to a higher temperature, the amount of water held in that way would vary; some of it would be expelled by expansion, and

the changes of density backward and forward would be readily accounted for.

Apart from this point he thought that the Author's logic was at fault in one or two places. For instance, he referred in his argument to the contact E.M.F.s, and he explained the fact that he obtained a negative result by saying that he did not succeed in getting rid entirely of one of the modifications. It occurred to him that a simpler explanation was that the Author did not produce a modification at all. In dealing with Stas's work, the Author said ; " By heating the metal *in vacuo* gas only can be expelled, and this would increase the density of the metal ; a decrease never can take place by this operation." Personally he ventured to think it could. If gas were expelled out of a piece of metal, assuming it to have been in solution in the metal or otherwise absorbed, and the volume of the metal was not reduced when the gas was removed, the density of the metal would fall, because in the same space where metal plus gas had existed only metal was now present. He thought it was quite an assumption to say that the removal of a gas from metal must necessarily increase the density of it. He desired also to refer to the Author's final conclusion, that " All physical constants of silver (excepting the atomic weight) refer to indefinite mixtures of the different allotropic forms." He thought the Author had pretty well disposed of his contention by that remark, because, of all the accurate physical work that had ever been done, some of the most accurate was the work on the silver voltameter which had been done by Mr. F. E. Smith at the National Physical Laboratory, and this work had been confirmed by similar work in Berlin and Washington. He thought it was correct to say there was probably no measurement which had ever been given with more absolutely consistent and accurate results than in that instance, and yet the members were told in the paper that such workers were dealing with an "indefinite mixture." He thought the answer was that those different forms must be so much alike in properties that the hypothesis that they were different at all might well be neglected.

Professor T. TURNER, M.Sc., Vice-President, said that Dr. Rosenhain had traversed a good deal of the paper, and though he had not exactly blessed it he had not called in question the accuracy of the work of the Author. The correctness of the conclusions might be called in question, but he thought all the members would acknowledge that the observations had been made with much skill. Like Sir Thomas Rose, he had failed to discover the third variety of silver, and it would be of interest if the Author in his reply would make quite plain where the third variety was. It might be the case that he considered there was one variety below 77° , one at 77° or thereabouts, and one above 77° , and if that was so it should be made clear. In any event it was perfectly obvious that there was no great volume change, and from the results of the calorimeter it was evident there was no great heat change. The

question naturally arose whether there was sufficient alteration at those points to lead one to consider that an allotropic modification had occurred. He was much interested in the figures that were given on page 94 for the ribbon metal which was made from the silver that was cast and then turned from chilled cylinders, because those results exactly agreed with the experiments made by Dr. Lowry and Mr. Parker* on the difference in density when metallic filings had been annealed.

It might be well to consider what happened when a piece of metal was being detached in the form of a filing or turning. What happened at the moment of tearing off? The material was being strained beyond its elastic limit; it was being stretched. Elongation occurred, and the piece would not break off until that elongation had taken place. The material was then in a state of tension; it was in consequence specifically lighter. If it were annealed or allowed to resume its ordinary condition it would become more dense. The Author took the density of the original silver as 10.4744; he kept it at a moderate temperature and the density became 10.4790; and on keeping it some days longer it increased still further to 10.4910. The density increased because the effect of the work in extending the metal was gradually passing away. The question might be asked whether that extended metal, which was largely amorphous, was an allotropic variety of the metal which had not been extended. That would depend to some extent upon a definition. Amorphous metal was really less dense than the crystalline metal. Even if a smooth polished surface was taken it was always strained and distorted by the process of polishing. It was strained metal which was specifically lighter than the unstrained metal. The Author had dealt in the paper with various kinds of metal, and, as Sir Thomas Rose had said, the changes of density observed on first working cast metals were due to the fact that little holes existed, and that those holes were more or less closed up by work at the first stage; and changes occurred during annealing because of the little bubbles of gas expanding. These changes tended to mask the effect to which he (the speaker) had previously referred. To some extent it might be true, as Dr. Rosenhain had stated, that liquid might have entered, but he did not think that would be marked in its effect when it was borne in mind that the material was surrounded the whole time by liquid, and, if that were the case, after a time the amount of liquid that would enter and leave would tend to become constant. It was not as though the metal were filled with air bubbles which went out and were replaced by liquid. If it had been first treated *in vacuo*, and was kept immersed, the effect of the liquid in the pores would not be very great. He would have been much interested to see what effect was produced on the density of silver if the Author had used a sheet of silver leaf. Following Faraday, the President had studied the effect of heat on silver. If

* *Journal of the Chemical Society Transactions*, 1915, vol. cvii. p. 1005.

a sheet of silver leaf were freely suspended in air and heated gently, it would be found that it gradually but very markedly shrank both in length and width. If it were stretched over a plate of glass, what was commonly known as transparent silver was obtained.* He could conceive that the Author might find several allotropic varieties of silver by his method of investigation, if he took the density of that sheet as it gradually began to pass from the smooth and extended form into the smaller sheet of metal with a large number of holes through which the light could be seen. At any rate, he suggested it was an interesting line of enquiry to ascertain what would be the effect of taking a piece of metal that had been so extended, and treating it with the same care that the Author had taken over the samples referred to in the paper.

Mr. SYDNEY W. SMITH (London) said that he had been much interested in the remarks of the previous speakers with regard to the interpretation which should be given to the very accurate density determinations made by the Author. He could find nothing in the work recorded in the paper which could not be explained on the lines which Stas had indicated, namely, that these apparent variations in density were primarily due to the absorption of gases by the metal and to their resultant effect in leaving the metal porous.

Dr. Rosenhain might have amplified his remarks by referring to his own work in collaboration with the late Donald Ewen.† In their investigations pure silver was subjected to prolonged heat treatment *in vacuo* and it was found that during the first heatings considerable losses of weight occurred owing to the expulsion of occluded gases. Their work showed that the expulsion of these gases *in vacuo*, even at temperatures approaching the melting point of silver, did not occur immediately, but extended over a considerable length of time. During this period, of course, the imprisoned vesicles expand and cause the apparent density to diminish. These expansions are generally made evident on the surface of pure silver by the appearance of "blisters" after it has been rolled and annealed.

The Author's comment on this apparent decrease in density, observed by Stas when silver is heated *in vacuo*, is therefore not justified and the explanation given by Stas is clearly the correct one.

By way of illustrating his interpretation of the Author's work he would give an analogy which was somewhat similar to that indicated by Professor Turner in his remarks.

Taking, as an extreme case of porosity, that furnished by pure spongy gold, prepared by parting an alloy of silver and gold, it would be found that after being immersed in water this gold existed in a completely waterlogged condition. If the density were now determined it would be found to be the same as that of pure, hammered gold,

* See T. Turner, *Proceedings of the Royal Society*, 1908, A, vol. lxxxi. p. 301.

† *Journal of the Institute of Metals*, No. 2, 1912, vol. viii. pp. 165, 166, and 175.

thing over 19. If the spongy gold were next dried and partially annealed, some of the pores would close up, but not completely. The density of the partly annealed metal would now indicate something over 13 instead of 19, and if left in the water for some time it would slowly increase as the metal became more and more waterlogged until the apparent density reached 14 or 15 or 16, although the full value of 19 would never be attained. That could only be done by re-melting the metal.

He thought, therefore, that the small increase in density, observed by the Author, was really due to the gradual waterlogging of the specimen, the fall of the meniscus in the capillary tube being, of course, the result of the absorption of water by the metal in the earlier experiments and of oil in the later ones.

With regard to the other observation, that at temperatures approaching or exceeding 100° C. the density began to decrease again, he thought there was no difficulty in explaining that, having regard to the diminution in apparent density by the expansion of the imprisoned vesicles to which he had already referred.

The apparent transition at about 80° which the Author had found, represented, he thought, a compromise between these balancing effects under the particular conditions of the Author's experiments. Up to that point the evidence of change of density was caused by the waterlogging of the air spaces to which the water had access, while beyond that point the evidence of change was caused by the expansion of the imprisoned vesicles of gas in the metal.

Mr. F. S. SPIERS (London) said that the ultimate test as to whether the physical changes observed by the Author were, or were not, allotropic must presumably rest on the existence of corresponding changes in other physical properties. Had the Author made measurements, for example, of the heat changes or the changes in electrical properties, if any, taking place at the transformation points, and if so, did they confirm the conclusions he had derived from the measurements described in the paper?

The PRESIDENT said that he was sure the members would feel that they were much indebted to the Author for having sent the paper to be read before the Institute, because it dealt with a question of theory which ought to be thrashed out—all the work done at the Utrecht University must be taken seriously—and a notable beginning had been made in that direction at the present meeting.

COMMUNICATIONS.

Dr. CECIL H. DESCH (Glasgow) wrote that it was difficult to follow some of the experiments described in the paper. For instance, whilst the general conclusion was drawn that the density of all the specimens of silver decreased at 100° or higher, but increased at 25° or 50°, reference to pages 93 and 94 showed that sample S₁ increased in density when heated at 100° for 72 hours. Moreover, the observed changes were so irregular, being sometimes large and sometimes small, that no general conclusions could be drawn. The failure to obtain any difference of potential in the experiments on pages 99 and 100 was also very significant. A metal which had been rendered partly amorphous by cold working would give a distinct difference of potential when tested against the same metal in the annealed condition, and it might fairly be expected that allotropic modifications would also give a measurable difference, even though the metal might not be completely converted.

The decrease of density of silver when heated in a vacuum, as recorded by Stas, was perfectly consistent with Stas's explanation of the influence of absorbed gas. The expansion of the gas would enlarge the cavities, with the result of diminishing the apparent density of the metal. This experiment in itself was sufficient to illustrate the danger of drawing any far-reaching conclusions from the changes of density of metals on heating, when unsupported by other evidence of a less ambiguous character.

Professor A. K. HUNTINGTON, A.R.S.M., Past-President, wrote that he was strongly of the opinion that occluded gases had a great deal to do with changes of density occurring during heating and cooling. Expansion of the gas on heating would render the metal more porous and consequently a given volume would be lighter.

Professor ZAY JEFFRIES (Cleveland, Ohio), wrote that, in his opinion, Dr. Helderman's results pointed almost beyond question to the fact that silver was allotropic. However, it did not seem clear to him that the author's results proved the existence of at least three solid allotropic forms as he stated on page 107. It had been shown by Le Chatelier that recently cold-worked, or strain-hardened, silver began to soften, that is, decreased in tensile strength at room temperature immediately after strain hardening. It was well known that the density and heat of solution of strain-hardened metals, with the exception of bismuth, were less than the same metals in the perfectly annealed state. It was understood, of course, that temperature regions in which allotropic changes occurred were to be excepted. It occurred to him (Professor Jeffries) that possibly some of the variations in density measurements might be due to the spontaneous release of the strain

hardening which was caused by turning the silver into chips. It was needless to say that these small chips would be quite severely strain hardened immediately after turning. The density measurements, however, pointed decidedly to allotropic changes, but he could not see from the results obtained why two solid allotropic modifications would not satisfy all of Dr. Helderman's experimental results.

Professor HENRY LOUIS, D.Sc. (Newcastle-on-Tyne), wrote that he desired to draw the attention of Dr. Helderman to the work which he did, a good many years ago, on the allotropism of gold.* He there showed that gold, as left behind by dissolving out the alloying metal from alloys of gold with other metals, e.g. silver, zinc, copper and lead, had a higher specific gravity than ordinary gold. It was also demonstrated that such gold differed from ordinary gold in its behaviour towards mercury. He suggested that Dr. Helderman should experiment upon silver upon similar lines to those which he found successful in the case of gold. Further, it would be well to study gold-silver alloys in the light of an observation of his in one of the above papers; he there pointed out that Matthiesen† found that the alloys of gold and silver have densities exceeding those calculated from their constituents in the ratio approximately of 1:0.997, and he (Professor Louis) suggested that this fact may be due to either or both of the constituent metals existing in some allotropic form.

Dr. A. E. OXLEY (Sheffield) wrote that he had read Dr. Helderman's paper with considerable interest and from his carefully conducted experiments he believed that Dr. Helderman's work disclosed some remarkable instances of the complex behaviour of silver under heat treatment.

The property which the author considered throughout his work in the present communication was that of density. Small pieces of silver were taken, subjected to various heat treatments and irregularities of density were discovered.

Now it was known that silver subjected to mechanical stress changed appreciably in density. Why was this? Each piece of crystalline silver consisted of a complex of grains, the molecules were regularly arranged throughout each but the boundaries of the grains were ragged, and so there must be interstices within the metal. It was to be expected, therefore, that applied pressure would distort the grains, causing them to occupy a smaller space and so increase the density. Stas showed that this was so. The increased density was maintained when the pressure was relaxed, therefore the metal remained strained internally. If the silver were heated the increased molecular agitation released the strain and the metal on cooling assumed the density it had prior to mechanical treatment.

* *Transactions, American Institute of Mining Engineers*, xxiv. (1894), p. 182 and p. 705; and xxii. (1893), p. 117.

† *Philosophical Transactions*, 1860, p. 177.

That seemed to be a perfectly natural result to get and there was no necessity to call into play either the question of occlusion* (Stas' explanation) or the possible existence of allotropic modifications.

Next, passing to the work of Berthelot, that afforded evidence of the existence of four varieties of silver as deduced from tests of the heat of solution. The samples of silver had various treatments, including rolling, heating in oxygen (which was absorbed by silver) and electrolysis. Was it suprising that the heat of solution varied? Probably if a sample had been hammered a fifth "allotropic" modification would have been discovered. Then by drawing out into a wire we might get a sixth. High pressure must distort the individual crystalline grains and strain the bonds holding the atoms in their crystalline configuration. That would change the heat of solution, for these strained bonds have to be overcome by the solvent.

Dr. Helderman was right, in his (Dr. Oxley's) opinion, when he said "it is not necessary to postulate the existence of so many different forms, in order to explain the phenomena observed."

It should be examined to what extent the new determinations of Dr. Helderman could be interpreted without resorting to the admission of allotropic modifications.

The experiments of Blake referred to on p. 88, in which four allotropic forms of silver were recognized optically, were not regarded by Dr. Helderman as conclusive proof that silver possessed allotropic forms but were due, he said, to change of size of the silver particles, which might be accompanied by change of colour.

Why should not the size of the crystalline grains be similarly affected by heat treatment? Below a certain temperature the grain might not be disintegrated—the thermal agitation not being sufficient; above that temperature, disintegration might take place. Then in the latter case, on cooling, the new sized grains would certainly not be packed with the same degree of closeness as in the original metal. Hence there would have occurred a change of density. Moreover, those grains would be in a strained condition. The strain might be sufficient to cause a re-building of the granular structure and, therefore, the return with time to the original density. The metal was probably in a supercooled state after the heat treatment and the crystalline grains would tend to readjust themselves. In another case disintegration of the grains might be brought about only by heat treatment in the presence of some chemical reagent.

It was perhaps well to bear in mind Hopkinson's work on the magnetic properties of nickel steel. Such steels lost their magnetism at the transformation temperature. On cooling they were practically non-magnetic till supercooled far below the temperature of transformation and then gradually passed over to the original magnetic form. That at least showed the possibility of rejuvenation of a crystalline

* Note that Stas took the *compressed* metal ($p = 10\cdot5104$) and heated this in a vacuum;
p. 85.

type in a solid, and other examples might be given. The return to the magnetic state had involved such a reconstitution of the grains that the molecules were now free to be influenced magnetically. That implies a change of density.

It seemed that the phenomena observed could equally well be explained if it were assumed that the molecular aggregates within the crystalline substance varied continuously in complexity with the temperature and, in addition, that the re-formation of those aggregates after a certain temperature had been passed could be temporarily resisted.

The A_2 transformation in pure iron could be explained in his (Dr. Oxley's) opinion by a continuous variation of molecular complexity with temperature and even at the A_3 transformation the only type of allotropy appeared to be the special one involving a modification of the electric and magnetic structure of the atom—a modification which might be called atomic allotropy,* which resulted in the formation of a new type of atom.

It seemed to the writer that the changes observed by Dr. Helderman, and those observed by the other experimenters whom he cites, did not warrant the recognition of a variety of modifications of the element silver such as the term "allotropic" implied.

The definition of allotropy advocated by some metallurgists was the one due to Nernst, based on *sudden* changes of physical or chemical properties. That definition was brought forward during a criticism of the writer's paper on the "Transformations of Pure Iron."† To what extent that definition was satisfied in the case under consideration was clear from Dr. Helderman's results.

The diversity of views as to what really constituted an allotropic change was astounding considering the scientific importance which attached to the term.

Nevertheless, the results which Dr. Helderman had obtained were of great value in extending the work carried out in the past by Professor Cohen and showed in a remarkable way the degree of complexity which even the purest elements could display.

In conclusion there were two questions that he would like to put forward: (1) What was the effect, if any, on the density of the silver samples of different rates of cooling? (2) In the dilatometer experiments how were the thermal after effects of the glass eliminated?

[Dr. Helderman's reply to the discussion had not been received up to the time of going to press: it is hoped to include it in vol. xvii.—ED.]

* *Transactions of the Faraday Society*, vol. xi. pp. 134, 149, and 156

† *Loc. cit.* p. 138.

THE DEVELOPMENT OF THE SPELTER INDUSTRY.*

By ERNEST A. SMITH, A.R.S.M., M.Inst.M.M.

It must be stated at the outset that this paper in its original form was submitted, on December 31, 1915, in competition for the Peter Le Neve Foster Prize of the Royal Society of Arts, and was awarded Honourable Mention.

It is now published at the request of the Council of the Institute of Metals, and with the sanction of the Council of the Royal Society of Arts, after some alteration (including both omissions and additions) to adapt it to the requirements of Members of the Institute.

Those interested in the spelter industry will do well to consult the excellent paper on "Zinc, its Production and Industrial Applications," † by Mr. J. C. Moulden, A.R.S.M., M.Inst.M.M., to whom the Peter Le Neve Foster Prize and a Silver Medal were awarded.

With the permission of Mr. Moulden a few quotations from his paper have been made, and these are duly acknowledged in the text.

HISTORICAL NOTE.

The first certain mention of zinc as a distinct metal is accredited to the alchemist Paracelsus (1493–1541), a contemporary of the renowned metallurgical writer Agricola. There are, however, strong reasons for the belief that the Chinese were acquainted with metallic zinc at least several centuries earlier.‡ There is also some evidence that the metal was known and extracted in India prior to the 16th century.

The localities of Eastern production have never been adequately investigated. Nevertheless, it is well known that the

* Read at the Annual Autumn Meeting, London, September 20, 1916.

† *Journal of the Royal Society of Arts*, 1916, vol. lxiv., (May 26th) pp. 495–573, (June 2nd) pp. 517–531.

‡ Gowland, Presidential Address, *Journal of the Institute of Metals*, 1912, vol. vii, p. 42.

Chinese have, from very early times, possessed considerable metallurgical knowledge, and it is not improbable that when the early history of the metallurgy of this ancient people comes to be written it will be found that the first separation of metallic zinc from its ores must be attributed to the Chinese.

There is evidence that the greater part of the zinc produced in the 16th and the 17th centuries came from China. The metal was imported from China into Europe and to the East Indies by Dutch merchants under such names as *tutinag* and *spiauter* or *spialter*; hence the English word *speltrum*, introduced by Boyle, and the English word "*spelter*," which is almost the only name for zinc in the works at the present day.

The earliest certain descriptions of zinc production in India seem to be some recipes for manufacture dating from the 11th to the 14th centuries, quoted by Praphulla Chandu Ray in his "*History of Hindu Chemistry*," London, 1902, p. 39. The crude distillation of zinc was conducted in Rajputana as late as the beginning of the 19th century, and the remains of such smelting in this and other districts are said to be very ancient. Whatever doubt there may be as to the antiquity of the discovery of metallic zinc, there appears to be little doubt that the art of zinc distillation was learned in the East and introduced into Europe in the latter part of the 18th century.

There is a tradition, recorded by Bergman, that an Englishman visited China in the 18th century expressly to learn the art of making zinc; that he attained his object and returned home in safety with the secret; and that some time afterwards works were erected at Bristol for the extraction of zinc by distillation *per descensum*.* This tradition is supported by the fact that zinc works were established at Bristol, about 1740, by John Champion, who was therefore, so far as we know, the founder of the British spelter industry, and also the first metallurgist in Europe to extract zinc from its ores commercially. Exactly what circumstances led Champion to start the spelter industry at Bristol must be more or less a matter of conjecture, but probably it was due to the fact that a calamine-brass trade had been in existence in England for about a century previously.

Formerly calamine, an important ore of zinc, was fairly abun-

* Quoted by Percy, *Metallurgy of Copper and Zinc*, p. 520.

dant in England and was employed for brass-making, and was also exported as ballast to the Continent to be used for the same purpose. It is recorded that calamine-brass works were erected in Surrey about the middle of the 17th century. Works were also established at Bristol about 1702, and afterwards at Cheadle, in Staffordshire, about 1720. Later, works were erected, for the manufacture of ingot-brass, at Smethwick, Swansea, and Llanelly.

Some fifty years after the establishment of the British spelter industry the extraction of zinc from its ores by distillation was introduced into Germany by Ruhberg, who first used the method in 1798 in the glass-works at Wessola, near Pless, Prussian Silesia. This was the beginning of the now famous Silesian zinc industry, which was based on the occurrence of rich calamine in the neighbourhood of large deposits of coal. Calamine had already been mined in the district for several centuries, and, as was the case in other parts of Europe, was used in the manufacture of brass.

A few years later zinc extraction was introduced into Belgium; its introduction being accredited to the Abbé Dony, who appears to have made the independent discovery of zinc production by distillation at Liége in 1805. Subsequently works were established at Moresnet to smelt the important deposits of zinc ores occurring in La Vieille Montagne, La Nouvelle Montagne, and Corfalie. The Belgian zinc industry soon became firmly established, and by the middle of the 19th century was a formidable rival to Germany in the amount of metal produced annually.

Both Belgium and Germany adopted the method of zinc distillation *per ascensum*, which proved to be more economical and more satisfactory than distillation *per descensum* as used in England. The latter method, which was also carried on in Carinthia and Hungary, was discarded in England in favour of the former method about the year 1850.

Towards the latter half of the last century zinc smelting was also started in Austria, Spain, and France, but the industry in these countries has never grown to very large proportions, the production, even at the present time, being insufficient to satisfy their own requirements.

During the 18th century the growth of the European zinc

industry was comparatively slow, owing probably to the somewhat limited uses of the metal at that time. Until the beginning of the 19th century zinc was mainly used for the manufacture of brass, but about this time it was found possible to roll the metal into sheets. When cast, zinc is highly crystalline, but when heated to a temperature of from 100° C. to 150° C. the crystalline structure is changed and the metal rendered malleable. This discovery was of no little importance, as it enabled the metal to be used for roofing and other purposes for which the higher-priced metal, copper, had hitherto been employed.

A patent for "a method of manufacturing the metal called zinc into wire and into vessels" was granted to Messrs. Hobson and Sylvester, of Sheffield, in 1805.

About thirty years later further impetus was given to the zinc industry by the employment of the metal for the manufacture of the so-called galvanized iron. The coating of zinc was originally deposited upon the iron surface by galvanic agency, hence the name, first given in France, and subsequently adopted in this country. This method, however, later gave place to the simpler method of coating the cleaned iron surface by simple immersion in a bath of melted zinc, a patent for zincing iron in this way being granted to H. W. Crawford in 1837.

The application of these two important properties of zinc greatly extended its use for industrial purposes, and the production of the metal very rapidly increased, until it soon took its place as third in the list of non-ferrous metals of industrial importance.

In 1830 the total production of spelter in Europe was less than 5000 tons, and in 1840, ten years later, the total output had only reached a little more than 17,000 tons. It was not until the middle of the 19th century that the industry began to be established on a sure footing in Europe.

Attention was given to zinc extraction in America in 1838, in which year the metal was first produced experimentally in the United States. The regular manufacture of zinc was not, however, undertaken until 1859, when J. Wharton started zinc smelting in muffle furnaces of Belgian type, with Pennsylvanian anthracite as fuel; this was the beginning of metallic zinc production in the United States on a commercial basis. By

1870 six works were producing spelter in the United States at the rate of approximately 4500 tons per annum, and about 13,000 tons* of zinc oxide.

While at this time the American zinc industry was only just becoming established the European industry had grown considerably, as shown by the following figures giving the spelter output for the various countries of Europe in 1870.

	Long Tons.
Germany	55,744
Austria	3,000
Belgium	45,745
Great Britain	15,000
France	4,400
Spain	4,400
Total European production, 1870	128,289

This, with 4500 tons of spelter produced annually in the United States, will make a total of approximately 133,000 long tons as the world's production of zinc in 1870.

It must be noted that although domestic zinc ores were mined in Europe at this time, a not inconsiderable quantity of imported ore was also smelted.

The enormous increase in the rate of production and in the demand for zinc during the past fifty years is shown in the following table, giving the world's approximate annual output and consumption of spelter at intervals of ten years :

Year.	European Production.	American Production.	World's Production.	World's Consumption.
	In Long Tons, 2240 lb.			
1870	128,000	4,500	133,000	...
1880	207,000	21,000	228,000	230,000
1890	...	...	343,000	345,000
1900	310,000	58,000	368,000	474,000
1910	557,000	247,000	804,000	820,000
1913	663,000	315,000	982,000	997,000

It will be seen that not only has there been an enormous increase of production, especially during the present century, but the ratios between the European and the American production have altered, implying far-reaching economic changes in regard

* Unless otherwise stated, all figures are given in the English long ton of 2240 lb.

to the supply and demand for spelter. Further particulars of the world's zinc industry are given later. It will be well now to trace briefly the more recent development of the European and American spelter industries.

PROGRESS OF THE EUROPEAN ZINC INDUSTRY.

As the result of the ever-increasing demand for spelter, the European zinc industry made rapid progress during the latter part of the 19th century, as indicated by the above figures.

Germany, taking advantage of her natural resources in zinc ore and coal, early took the lead as the largest producer not only in Europe, but in the world. For many years Germany remained the chief zinc producer, but in recent years the first place has been taken by America.

The chief zinc-smelting centre of Germany is Silesia, the output from this district being about two-thirds of the total zinc production of the German Empire, the remainder coming chiefly from the Rhine district and Westphalia.

The actual production (in tons) of spelter from these two districts in recent years is shown in the following table :

District.	1904.	1909.	1910.	1911.	1912.	1913.
Silesia	124,000	137,483	138,040	153,715	166,425	167,431
Rhine district and Westphalia . .	64,355	73,985	86,120	92,735	100,370	91,385

The Silesian zinc industry is limited to the extreme south-eastern part of Prussia, in a rather narrow strip of territory between Russia and the Austrian frontier.*

Established, as already stated, in the latter part of the 18th century, it was prior to the War an industry of considerable magnitude, taking a prominent part in supplying the European markets with zinc.

Formerly the metal was produced entirely from ores mined in the country, but in recent years considerable amounts of ore have been imported. The smelting of zinc blende has led here, as in other places, to the establishment of very perfect arrangements for utilizing, and preventing the deleterious effects of the sulphurous

* "The Silesian Zinc Industry," G. P. Scholl, *Mining Magazine*, 1905, vol. xii. pp. 206-212.

acid generated in the roasting of the ore. Most of the works are equipped with roasting furnaces for using the gases for the manufacture of sulphuric acid.

Austria is a comparatively small zinc producer, although the output has gradually increased in recent years. The amount produced in 1913 was 21,000 tons. The larger proportion of the metal is turned out at the works in Galicia, whilst rather less than 50 per cent. is produced at the works at Steiermark.

Belgium early became the second largest zinc producer in Europe, the works being situated in the neighbourhood of Liège.

The Belgian output of zinc has steadily increased for some years, and has now reached nearly 200,000 tons annually. A large proportion of the metal is rolled into sheets and exported. A small quantity of the metal is used for the manufacture of zinc oxide. The works are in the hands of the well-known Vieille Montagne Company, which has works or mines not only in Belgium, but also in France, Germany, Sweden, England, Algeria, and Italy.

As previously stated, France (Pontgibaud), Spain, and Holland are also zinc producers of Europe, and produce substantial amounts annually, though not enough for their own needs. The annual zinc production in these countries in recent years is given later in Table I.

With regard to the English spelter industry, the ores of zinc which are to be found within the limits of the British Isles do not equal in importance those of some foreign countries ; and accordingly, although the various applications of zinc have greatly increased within the last few decades of years, the home production of the metal has had to struggle against the superior advantages of some of the foreign sources of supply.

The output of spelter in Great Britain is comparatively small, being about one-fifth of that annually produced by Germany, the largest European producer. The annual production for the past ten years has remained steadily between 50,000 tons and 60,000 tons. In 1913 Great Britain produced 58,200 long tons, or 6 per cent. of the world's total, as compared with 56,300 long tons in 1912.

The chief zinc-smelting centre in Great Britain is Swansea, where the well-known firm of Vivians erected spelter works as early as 1835. There are also twelve works in different parts

of the country, where zinc is extracted from concentrates and from zinc-bearing products such as galvanizer's residues, &c. Broken Hill concentrate is treated by the distillation process at the Sulphide Corporation's works at Seaton Carew, Durham. These works are now being considerably extended.

During the past few years a very pure quality of zinc has been produced by a special wet process at the works of Messrs. Brunner, Mond & Co., Ltd., at Northwich, Cheshire, to which reference is made later.

PROGRESS OF THE AMERICAN ZINC INDUSTRY.

Although started more than half a century later than the important zinc industry of Germany, the American industry has grown so rapidly that since 1906 it has taken first place in the world's production of zinc.

This rapid growth of the zinc production of the United States affords a striking illustration of the speed with which industrial enterprises develop, under the combined influence of great natural resources and of modern machinery used with intelligence and skill. The possession of very large quantities of raw material, in the form of zinc ore and of coal and natural gas as fuel, has enabled the United States to rise rapidly, within a comparatively few years, to the position of the largest zinc producer and exporter among the zinc-producing communities of the world. With the growth of the industry works were established in the States of Illinois, Kansas, and Missouri, which produced about two-thirds of the American total zinc output, the remainder being produced in a few Eastern and Southern States.

Formerly a special feature of the American zinc industry was the utilization of the natural gas wells of Kansas and Oklahoma for smelting purposes, but owing to the partial exhaustion of these in recent years it became necessary to transfer the works to Illinois and other places where coal or oil is cheap.

At the end of 1914 the total number of zinc-smelting plants in the United States was 33, 10 of which were in Illinois, 9 in Kansas, 6 in Oklahoma, and the remaining 8 in the States of West Virginia, Missouri, Pennsylvania, and Colorado. The works

are independent of each other, so that the competition for ore is keen.

ASIATIC ZINC INDUSTRY.

The Asiatic centres of zinc production, although small, are by no means unimportant.

China has, for several centuries, been a producer of the metal by crude distillation by native methods in pots, and considerable quantities of spelter made in this manner have found their way to the European and other markets. According to T. T. Read,* the exports of zinc from China have increased about fourfold in the past four years. The quality of the metal, which is produced chiefly in Kweichow, is stated to be very good, containing 99.56 per cent. of zinc with a little lead and iron.

Zinc smelting in Japan appears to be of recent origin, although zinc ores have been mined and exported for many years. The present smelting works are situated at Ohmuta and Osaka, the former producing about twice as much spelter as the latter. The total combined capacity is given as 600 tons per month. The output in 1914 reached a total of about 47,000 long tons, but this will be increased in the near future as the Ohmuta smelters are adding another ten furnaces to their plant, which will bring up the total capacity of their works to about 14,000 tons per annum.

This appears to be an effort to supply home demands and reduce imports, since in 1913 the spelter imported into Japan in the form of blocks and sheet was 10,900 tons, while in 1914 it was only 5800 tons.

PRESENT-DAY ZINC-SMELTING CENTRES AND OUTPUT OF SPELTER.

A prominent feature of the zinc industry has always been its limitation to the comparatively few smelting centres in Europe and America, already mentioned, viz. Silesia, Westphalia, and Belgium on the Continent, Swansea in England, Illinois, Kansas, and New Jersey in the United States. These are the more important smelting centres contributing to the world's supply of

* *Mineral Industry*, 1915, vol. xxiii. p. 793.

zinc ; and to one or other of these centres practically all zinc ores are shipped for treatment.

This localization of the zinc industry is due to the necessity for cheap fuel, the occurrence of fireclay required for the retorts, and the necessity for skilled labour, while the climatic conditions must be suitable to the trying conditions of the workers.

The American zinc industry has always been independent of the European industry. The main difference between the two industries at the present time is, that while European smelters are almost entirely dependent on imported ores, American smelters have enormous domestic deposits on which to draw. They are, however, handicapped in the quality of the American fireclays, which are inferior in fire-resisting properties to the European clays for retort-making.

Mention must be made of two plants installed a few years ago at Cockle Creek and Port Pirie in Australia, which as yet are of little effect on the world's zinc production, in view of the large amounts of zinc concentrate shipped, before the present war, to Europe from Broken Hill, but which, in view of the decision of the Broken Hill Proprietary Company to considerably increase its number of furnaces, will undoubtedly become more important.

The efforts that are being made in the zinc industry to cope with the very abnormal conditions prevailing as the result of the war are considered later.

The status of the world's zinc industry, prior to the war, is well shown in the following tables, which give the figures for the production and consumption of spelter in all the principal countries for ten years ending 1913, and also the average price in the London market.

The figures also show the progress that has been made in each case.

The bulk of the metal produced will have been obtained direct from ore, but a fair proportion, possibly about 23 per cent., will consist of re-melted metal recovered from scrap metal, sweepings, skimmings, drosses, &c. In America metal produced direct from ore is termed "primary zinc," while that resulting from re-melting is known as "secondary zinc."

The estimates of consumption take no account of any stocks which may exist, and, hence, theoretically, the total consumption

TABLE I.—*Production of Spelter.*

Compiled by Henry R. Merton & Co., Ltd. (London).

Countries.	Spelter (in metric tons, 1000 kilos = 2204·6 lb.).*									
	1904.	1905.	1906.	1907.	1908.	1909.	1910.	1911.	1912.	1913.
Germany	191,060	197,184	205,023	208,707	216,876	220,080	227,747	250,393	271,064	283,113
Belgium	139,982	145,592	152,461	154,492	165,019	167,100	172,578	195,092	200,198	197,703
Holland	13,099	13,767	14,650	14,990	17,257	19,548	20,975	22,733	23,932	24,323
Great Britain	46,216	50,927	52,587	55,395	54,473	59,350	63,078	66,956	67,231	59,146
France and Spain	49,082	50,369	53,786	55,733	55,819	56,118	59,141	64,221	72,161	71,023
Austria and Italy	9,248	9,357	10,780	11,359	12,761	12,638	13,305	16,876	19,604	21,707
Russia	10,606	7,642	9,610	9,738	8,839	7,945	8,631	9,936	8,763	7,810
Norway . . . . .	...	...	...	...	...	...	...	6,680	8,128	9,287
Production in Europe	459,293	474,800	498,897	510,614	531,044	542,779	565,455	632,887	661,081	673,912
" " United States of America	165,850	183,245	202,092	226,838	189,941	240,446	250,627	267,472	314,512	320,283
" " Australia	290	650	1,026	996	1,087	...	508	1,727	2,296	3,724
Total	625,400	658,700	702,000	738,400	722,100	783,200	816,600	902,100	977,900	997,900
Yearly average price	£22 : 11 : 10	25 : 7 : 7	27 : 1 : 5	23 : 16 : 9	20 : 3 : 6	22 : 3 : 0	23 : 0 : 0	25 : 3 : 2	26 : 3 : 4	22 : 14 : 3
Average monthly price—Highest . . . . .	...	...	...	...	...	23 : 3 : 4	24 : 1 : 9	27 : 12 : 6	27 : 5 : 10	25 : 19 : 1
" " Lowest . . . . .	...	...	...	...	...	21 : 6 : 3	22 : 1 : 1	22 : 19 : 2	25 : 8 : 10	20 : 11 : 2

* To convert to English long tons, multiply by 0·842.

TABLE II.—*Consumption of Spelter.*
Compiled by Henry R. Merton & Co., Ltd. (London).

Countries.	1904.	1905.	1906.	1907.	1908.	1909.	1910.	1911.	1912.	1913.
	Spelter (in metric tons).									
United States	157,100	179,000	200,000	227,900	188,300	246,900	244,500	251,600	312,900	313,300
Germany	151,600	162,700	179,300	174,400	180,200	188,100	184,500	219,300	225,800	232,000
Great Britain	129,100	136,000	140,500	140,700	138,500	155,500	177,800	175,700	185,200	194,600
France	67,200	59,700	63,400	69,600	77,900	66,900	56,300	82,000	82,000	81,000
Belgium	52,000	49,100	51,000	55,000	68,000	64,600	76,500	73,700	77,200	76,400
Austria-Hungary	25,300	26,200	28,300	30,300	32,600	32,800	33,800	43,500	46,800	40,400
Russia	23,500	26,000	17,000	17,600	17,800	18,400	24,900	28,900	27,900	33,300
Italy	5,100	5,600	6,200	7,100	8,400	8,200	8,100	10,100	10,700	10,900
Spain	4,000	4,700	4,700	4,800	5,000	4,500	4,200	4,800	4,700	5,900
Netherlands	3,700	3,800	3,800	3,800	3,800	4,000	4,000	4,000	4,000	4,000
Other countries	10,700	11,000	11,000	12,000	10,000	9,000	12,400	17,800	19,700	20,900
Total	629,300	663,800	705,200	743,200	730,500	798,900	827,000	911,400	996,900	1,012,700

should yield the same figures as the total production. Taking into account stocks at German works, the actual consumption of spelter in Germany during 1911 was about 217,900 tons, in 1912 about 220,800 tons, and in 1913 about 221,800 tons. When the stocks of other countries are taken into account the returns show that for the past few years, prior to the war, the production was in excess of the consumption.

THE ZINC MARKET.

London is the principal European zinc market, the price of the metal being quoted in £ s. d., according to the prevailing prices, for G.O.B. ("Good ordinary brands," or "Good ordinaries") and a slightly higher quotation for "Specials," the purer quality of zinc. The different brands of German spelter and the several selling centres of the German Empire are as follows :

C.G.H. brand of Silesian zinc sold at Breslau; W.H. and S.S. brands of Rhine zinc sold at Cologne, and refined Galmiun and Blende zinc sold at Frankfort-on-Maine. The price is always quoted in Marks per ton, the difference in price between each brand being usually 1 or 2 Marks, the first named being the cheapest brand.*

The conditions prevailing in the American spelter market, which is almost entirely independent of that of the rest of the world, have been summarized, recently, by C. H. Fulton † as follows :

"The main market or basing point for spelter is St. Louis, Missouri, for the reason that the great zinc fields and a large number of the smelting plants for zinc are situated not far from St. Louis. However, the large consumption of spelter is at places between St. Louis and New York, and it is sold in New York on a St. Louis basis, the quotations being given in cents per pound. The New York price is the St. Louis price plus 15 cents per hundred pounds, which is the freight rate on spelter from St. Louis to New York. The American market is in part independent of the European market, because spelter is protected by an import duty

* *Journal of the Society of Chemical Industry*, vol. x., 1891, p. 959

† *Technical Paper* 83, Bureau of Mines, Washington, 1915, p. 38.

of 15 per cent. *ad valorem*, and zinc in ore by a duty of 10 per cent. *ad valorem*.

"In the marketing of zinc, it is customary for the producer to sell direct to the manufacturer. This policy, however, in view of the large number of producers, is not nearly so closely followed as in the selling of copper, and some of the producers, particularly the smaller ones, sell to anyone who cares to purchase. This condition of course gives rise to more speculation in zinc than in copper. The real spelter market is established by the private transactions of producer and consumer, and any information as to the state of the market can come only from them. The facilities for exchanging information in the spelter market are not as good as those in the copper market, and hence transactions between producer and manufacturer often show considerable difference in price.

"There are four kinds of spelter on the market, the names of which, with the permissible proportions of impurities, are given in the accompanying table.

Grades of American Spelter.

Designation.	Proportion per Cent. of:			
	Lead.	Iron.	Copper.	Total Proportion of Impurities.*
A or high grade . . .	0.07	0.03	0.05	0.10
B or intermediate . . .	0.20	0.03	0.05	0.50
C or brass special . . .	0.75	0.04	0.75	1.20
D or prime Western . . .	1.50	0.08	...	...

"The grade produced in largest amount is prime Western, a considerable part of which is used for galvanizing iron and steel wire and iron plate. Brass special is used chiefly in the manufacture of brass goods. The price of high-grade spelter is usually 2 to 4 cents per pound more than that of prime Western. The high-grade and intermediate spelters are made by only a few smelters, but the brass special and prime Western are made by many concerns."

* Each grade is free from aluminium.

THE SPELTER CONVENTION.

Until the outbreak of war the spelter industry was largely controlled by the Spelter Convention, formed in 1909 and elaborated in 1910. It consists of three groups:

Group A, known as the Verband or German Syndicate, comprises the associated German and Belgian makers, whose output is disposed of by a joint selling office.

Group B comprises certain Belgian and French producers.

Group C comprises the British producers.

The two latter groups comprise the International Zinc Works Union.

On December 18, 1913, it was agreed to renew the International Convention until April 1916, and the German Syndicate followed suit, being prolonged until the same date.

The new terms are very similar to the old, but restriction of production is made a little more prompt. Stocks are taken quarterly, and when these amount to 50,000 tons, and when the average price has for four months been below £22 a ton (London), restriction of output comes into force. On October 1, 1913, pursuant to this provision, the Convention ordered a reduction of 8 per cent. in output. The new terms require that the price run below £22 for two months only. Out of the total world's production of zinc of 957,000 long tons in 1912, nearly one-third (354,000 tons) were controlled by the German Syndicate, and nearly 571,000 tons by the International Syndicate.

ORES OF ZINC.

The zinc of commerce is obtained chiefly from blende (termed sphalerite in America) and calamine, or smithsonite, the natural sulphide and carbonate of the metal respectively, which constitute the most important ores of zinc. Ores of less importance are the zinc silicates, hemimorphite or electric calamine, hydrous zinc silicate, and willemite, zinc silicate. Zincite, the red oxide, also occurs in some ores.

Although formerly calamine was the most important ore of zinc, at the present time zinc blende is the chief source of the metal. When pure, blende contains 67 per cent. of zinc, but iron

sulphide is nearly always present in considerable quantity, so that the ores as received at the smelting works usually contain from 30 to 55 per cent. of zinc. Blende often contains cadmium to the extent of about 3 per cent., which may be profitably extracted. Silver is also sometimes present in sufficient quantity to permit of profitable extraction. Zinc blende is very widely distributed, and occurs in large quantity in most countries in Europe, and in America.

Calamine is decreasing in importance as an ore of zinc, since the deposits in many localities are more or less exhausted. The present supplies are largely derived from Upper Silesia, Austria, Italy, Greece, and Algeria. When pure calamine contains 52 per cent. of zinc, but it is usually accompanied by oxide of iron, carbonate of lime, &c., which depreciate its value, since these substances give trouble in smelting if present in appreciable quantities.

Commercially, the term calamine includes also zinc silicates, as these are generally associated with calamine. Hemimorphite occurs in considerable quantities in the Island of Sardinia, while willemite occurs with calamine near Aix-la-Chapelle. Both these silicates also occur in franklinite, an ore containing iron, manganese, and zinc, in which the zinc varies considerably, but may reach 21 per cent. It occurs in considerable quantities only in New Jersey, in the United States.

The willemite associated with the franklinite is separated by a magnetic process, and is treated for the extraction of the zinc. The franklinite is then treated for the production of zinc white, *i.e.* zinc oxide, leaving a highly manganiferous residue, which is smelted in blast-furnaces for the production of spiegeleisen, a rich iron-manganese alloy.

Within recent years the zinc ore market has been considerably augmented by the supply of thousands of tons of zinc concentrate, a high-grade product, resulting from the mechanical treatment of low-grade ores and so-called complex ores, in which the zinc is intimately associated with other metals, such as lead, copper, and silver. Many millions of tons of such material have been located in different parts of the world, especially in America, and in some cases partially developed. Such ores have been the subject of much experiment, with a view to the profitable extrac-

tion of the several valuable metals they contain. Where ores are sufficiently high in zinc blende and lead, and carry little or no iron pyrites, or chalcopyrite, the ordinary methods of water concentration in jigs, and upon tables, such as is employed at Joplin and some of the Leadville mines in the United States, give satisfactory separation.

For ores, however, with iron pyrites, and more especially with chalcopyrite, where the differences of specific gravity are so small, special devices using magnetic separation, static and dielectric methods, as well as dry concentrators, are employed, and at Broken Hill, in Australia, where the ore consists of a very intimate association of blende and galena, a number of flotation processes has been developed. There is little doubt that the zinc of the future will be derived largely from concentrates obtained from low-grade and complex ores by such methods as those just mentioned.

At the present time the chief sources of the world's supply of zinc ores, including concentrates, are the United States, Australia, Germany, Italy, Spain, Algeria, and Tunis.

EUROPEAN SOURCES OF ZINC ORES.

Dealing first with the European sources of zinc ore, the chief producer is Germany, the most important deposits being situated in Upper Silesia, some also occurring, however, in the Rhenish provinces and in Westphalia. The ores of the Silesian district are principally calamine and blende. Oxidized ores were treated exclusively in the Silesian district until about 1860; since then blende also has been worked, and is now by far the more important ore smelted.

The larger proportion of the zinc ore mined in Germany comes from the Silesian district, the output, which has steadily declined in recent years, amounting to between 650,000 long tons and 700,000 long tons per annum. In 1913 the production amounted to 627,000 long tons, a decline of about 10,000 tons on the previous year.*

Austria-Hungary is also a zinc ore producer, the ore being

* The statistics relating to ore production in this paper are mainly derived from *The Mineral Industry*, 1915, vol. xxiii.

derived mainly from the provinces of Carinthia and Tyrol, though it appears in small quantities in Styria and other provinces. In 1913 the total output of zinc ore in Austria-Hungary amounted to 31,000 long tons; of this amount about one-half was devoted to Government use. The annual output has remained about the same for the past five years.

The most important Belgian zinc ore deposits were formerly those of La Vieille Montagne, La Nouvelle Montagne, and Corfalie. These have long since ceased to yield the large quantities of ore formerly obtained, and for some years the output has been gradually declining. The present production is about 11,000 long tons annually, the ore being entirely blende.

France's contribution to the supply of zinc ores has fallen considerably within the last few years, the output for 1913 amounting to only about 45,000 long tons, compared with 95,000 long tons in 1909. The production for each of the years 1911 and 1912 was slightly smaller than that for 1913. The French colonies, Algeria and Tunis, have been important producers of zinc ore for some years, especially the former, which in 1913 produced 81,000 long tons compared with 83,000 tons for the previous year. The total output for Tunis amounts to about 35,000 long tons annually.

In Spain there are forty-four productive zinc ore mines, the most important being in the provinces of Murcia, Santander, and Cordoba. About 175,000 long tons of zinc ore are mined annually, a considerable proportion of which is exported to the various European zinc-smelting centres. Owing to the prevailing low prices, the exports of ore declined in 1913.

Both blende and calamine are produced in Greece, mainly from the mines of Laurium, the production for 1913 being about 30,000 long tons of blende and 20,000 long tons of calcined calamine, a total of 50,000 tons, showing a decrease of some 17,000 tons on the previous year.

Oxidized zinc ores are mined in Poland, near the German frontier, in the government of Kielce, the average production from three mines in this district being about 65,000 long tons per annum. The production has shown no increase for the last seven years.

Russia is also a producer, but the refractory nature of the

pyritic ores and the cost of transportation are unfavourable to the development of the zinc industry. Oxidized ores are mined in the East Siberian coast districts, but are smelted in the country and not exported.

With regard to the United Kingdom, the occurrence of zinc ores cannot be considered as extensive, although ores of zinc, combined with lead ores, are found in many counties in England and Wales and in the Isle of Man, also in Scotland. Calamine was formerly mined, but at the present time the ore is almost entirely blende, the largest producers being the Nenthead and Nentsbury mines at Alston, Cumberland, and the Carshield mine, Northumberland.

The total output of dressed zinc ore for the United Kingdom is about 17,500 long tons per annum.

The Alston mines in Cumberland have for some years been owned and worked by the Vieille Montagne Spelter Company of Belgium, and the ore produced at these mines, and one or two other north country mines, is shipped chiefly to Belgium for treatment. The total weight of British zinc ore exported from the United Kingdom in 1913 was 13,378 tons, of which 11,260 tons were consigned to Belgium and 1960 tons to France. In 1912 the total export of zinc ore was 11,139 tons.

The ownership and working of the British mines by foreign companies, and the exportation of the ore to foreign smelting centres, is not very creditable to the British mining industry, especially when it is remembered that practically all the zinc ore smelted in this country is imported. In 1913 the total imports of zinc ore by British smelters amounted to approximately 65,000 long tons, which was derived mainly from Australia, Italy, Algeria, Germany, Spain, and France.

AMERICAN SOURCES OF ZINC ORES.

Turning our attention now to the American continent, we come to the largest producer of the world's supply of zinc ores. The ore is obtained from a large number of comparatively small mines in the United States, of which Missouri, Kansas, Colorado, Montana, Wisconsin, and Oklahoma are the chief producing States.

The three States first named are responsible for nearly 50 per cent. of the total annual output of zinc ore in America.

The first zinc mines which were extensively, and successfully, worked are situated in the famous Joplin district of Missouri, and in the adjoining State of Kansas, from both of which many thousands of tons of high-grade ore of carbonate, silicate, and sulphide have been produced. During the past few years, however, there has been a temporary halt in the yield of high-class ore in America. The older Missouri and Kansas zinc district is not expanding, and is in fact beginning to decline as a high-class ore producer, though the Oklahoma and Wisconsin districts are increasing their output.

Considerable attention is also being devoted to lower-grade and more complex ores, the exploitation of which ore deposits have hitherto been more or less neglected owing to the richness of the Joplin and other districts. Ores of this class, as already pointed out, are submitted to concentration processes, consequently zinc ores, as purchased by the American smelters, at the present time, consist largely of concentrates. The exploitation of low-grade and complex zinc ores in America is, however, behind the practice in Europe and Australia, where the art of utilizing unpromising ores has had to be more closely studied. So far, in America, the greatest tonnage of zinc ore concentrate has been produced by magnetic separators, without including the enormous separating plant at Franklin Furnace, New Jersey, with its capacity of nearly one thousand tons daily, for the separation of franklinite from willemite. There seems to be little doubt that in the near future mines and districts in the United States not hitherto identified with zinc will become producers of zinc ore.

The Butte and Superior mill in Montana is adding considerably to the output of this State, and there is every probability that the Butte district will, within a few years, be an important source of zinc ore. Anaconda will also probably follow the example of the Butte district.

Formerly the chief zinc mining district in the United States was Joplin in Missouri, but more recently other States, chief among which is Colorado, have come prominently to the front as producers of zinc ore, and have steadily increased their output.

The famous Joplin district includes Jasper, Newton, and Lawrence counties; Ottawa county (Oklahoma) and Cherokee county (Kansas) are also included. The south-western corner of Wisconsin, including Lafayette, Grant, and Iowa counties, has long been known as the Wisconsin zinc and lead district. The adjoining portions of Illinois and Iowa are also included in this general district, as here the same ores are mined, but to a much less extent than in Wisconsin.

Up to about 1860 this district was the most important source of lead in the United States, but zinc ore was not recognized, or if recognized its importance was not appreciated. About 1860, however, zinc ore began to be mined, and its production increased until it became the most important metal of the district.

In 1902 and 1903 mining became more active, and since then there has been in the district a decided boom in mineral production, especially in zinc ore. The revival of the mining industry in this district in recent years is largely due to the introduction of plant for the magnetic separation of blende from its associated iron sulphide, thus giving a shipping ore of sufficiently high grade suitable for distillation. During 1914 there were forty-six mills and five magnetic separating plants in operation at various places in the Wisconsin district.

Some idea of the total zinc ore production of the United States may be gathered from the report of the zinc smelters, who are stated to have smelted in 1914 approximately: *

		629,000 short tons of blende.
		227,000 " " of calamine.
Total	.	<u>856,000</u> short tons.

This total will probably include some 21,000 short tons of ore imported from Mexico in 1914, and 11,000 tons from Canada. On the other hand, a small quantity of ore, amounting to 11,000 short tons, was exported to Europe. As previously stated, zinc ores imported into the United States are subject to a duty of 10 per cent. *ad valorem*, the basis of Customs appraisal being the foreign market value of zinc ores, minus charges, duties, and incidental expenses.

* *Mineral Industry*, 1915, vol. xxiii, p. 770.

AUSTRALIAN AND OTHER SOURCES OF ZINC ORE.

The well-known deposits at Broken Hill are the most important sources of zinc ore in the British Empire. The ore, which is highly argentiferous, consists of a complex association of galena and blende, with a gangue mainly composed of rhodonite, quartz, and garnet.

The ore is crushed and submitted to concentration and separation processes which give two main products, viz. a lead ore concentrate containing 65 per cent. lead, 6 per cent. of zinc, with varying quantities of silver, and a zinc concentrate containing about 46 per cent. zinc and 8 per cent. lead, with some 15 ounces of silver per ton. Except for the ore smelted at the plant of the Broken Hill Proprietary Co. at Port Pirie, S. Australia, and about 20,000 tons exported to England and smelted at the Sulphide Corporation's works at Seaton Carew, Durham, the whole of the zinc concentrates in the past has been sold under long-term contracts to smelters in Belgium and Germany. Formerly the ore was worked only for lead and silver, and in 1904 some 300,000 tons of tailings from the dressing operations, and running at about 17 per cent. of zinc, had accumulated at Broken Hill, besides large quantities which had been used for stope fillings.

After many experiments these tailings accumulations have, through the application of flotation processes of concentration, become a very substantial source of supply for the world's zinc. Since the outbreak of war the shipments of concentrates has been largely suspended. In normal times the output of zinc concentrates was approximately 500,000 tons annually, but in 1914 the output amounted to only 359,310 tons, being 147,350 tons less than the previous year, and representing a fall in value of over £500,000.

Deposits of zinc ores occur in various parts of Canada and British Columbia, but at present the output is not large. Most of the ore is mined in British Columbia and shipped to the United States for smelting. Efforts are, however, now being made to develop the zinc-smelting industry in the country. A considerable quantity of the zinc ore is in the form of concentrates derived from the treatment of the silver-lead deposits. The production

in British Columbia in 1914 was about 13,000 short tons, nearly twice the amount produced in 1913.

Considerable quantities of zinc ore have been mined in Mexico in the past, and exported to America and to Europe, but the unfortunate political conditions prevailing in the country in recent years have prevented producers from taking advantage of the more favourable import duties on ores entering the United States. Conditions limiting the shipment of zinc ore from Mexico have, however, now improved somewhat, so that a larger output of ore than for the past two years is to be expected in the future.

In 1909 the ore imported by America, from Mexico, amounted to 105,000 short tons, but since that time the output has fallen considerably, amounting to only 18,000 short tons in 1913, and 21,000 short tons in 1914.

Brief reference must be made to Asiatic sources of zinc ore. Zinc ores occur abundantly in China, in the Heng-Chou and Yang-Chou prefecture of Hunan province, and not inconsiderable quantities of ore have been exported annually to Germany. Lead-zinc sulphide deposits occur in Southern Hunan, but the important Sui-ku-shan mine, worked by the Hunan Board of Mines, is the only one in the district in active operation. The ore is argentiferous galena, associated with blende, iron pyrites, and calcite. A considerable proportion of the ore mined is dressed at the mine. The dressed blende and mixed zinc-lead sulphides are sold to the German firm of Messrs. Carlowitz & Co., having an ore-dressing plant at Woo Chang, where the material is further separated, previous to exporting it to Germany to be smelted.

According to T. T. Read,* the total output in 1914 was nearly 23,000 short tons of zinc concentrate, the coarse concentrate containing 53.4 per cent. of zinc, and the fine concentrate from 30 to 35 per cent. The Company is considering the desirability of erecting a smelter in China.

An important deposit of silver-lead-zinc ore, high in silver and remarkably free from gangue, occurs at Bawdwin, Tawnpeng State, Upper Burma, and there is a prospect of this district becoming an important producer of zinc.

Japan supplies an increasing quantity of zinc ore annually.

* *Mineral Industry*, 1915, vol. xxiii. p. 793.

Zinc ore is mined in many localities within the Japanese Empire, the greater part of which is exported, chiefly to Belgium.

The exports amounted to approximately 15,000 long tons in 1908, 18,000 tons in 1909, 22,000 tons in 1910, and 23,000 tons in 1911. The annual production at the present time is about 30,000 long tons. In 1913, 1200 long tons of Japanese zinc ore were imported by England.

EUROPEAN ZINC ORE TRADE.*

Owing to the shortage of the supply of domestic ores, the European smelters have had to rely more and more on imported ores, and this has resulted in a considerable European ore trade. For some years, considerable quantities of zinc ore have been shipped to Antwerp and to Swansea, from Sardinia, Algeria, Australia, and also in recent years from America. Despite the growing disposition of the American smelters to adapt their works to the handling of all classes of ores, the shipment of zinc ores from America to Europe has been important, and the tendency before the war appeared to be for the shipments to increase rather than to decline. The ore is shipped to Antwerp in bulk, as no sacks appear to be proof against the acid nature of the ore.

It arrives in the condition of fines, having been generally calcined, if calamine, and roasted, if blende. The cargo is sampled by reserving one basket in twenty-five during unloading. The ore reserved for sample is sampled by machinery, or mixed and quartered down to obtain a small quantity for assay in the usual manner. Settlements are made in Antwerp on the results of the assay. The ores are bought on different formulæ, all of which are based on the London quotation for spelter, the content of zinc in the ore, the loss of zinc in smelting, and the cost of carriage and smelting. For example, on the grades running from 46 per cent. of zinc and over, the bidding is usually on the following basis: they pay for the metallic content of the ore, less 8 units, 95 per cent. of the London price for spelter, G.O.B. ("Good ordinary brands"), less a smelting, or as it is called, a returning charge, which is determined by the analysis of the average sample submitted. This formula is only quoted on consignments c.i.f. Antwerp

* Vide *Mining Magazine*, 1905, vol. xii. p. 227.

(costs, insurance, and freight paid to Antwerp). Such a formula is eminently fair to both the seller and buyer. The selling price for London spelter is usually the average of the daily prices for the month previous to arrival. A type of formula used for calculating the value of zinc ore is : *

$$V = 0.95 P (T - 8) - R,$$

where V is the value in £ per ton,

P the price of spelter (good ordinary brands) in London,

T the percentage of zinc in the ore,

R the returning charge (i.e. cost of smelting per ton), but the value is affected adversely by the presence of impurities, such as lead (which should not exceed 3 per cent.), iron, and manganese (which should not exceed 10 per cent.), and fluorspar.

The following approximate figures, making a total of nearly 900,000 tons, of the European zinc ore trade in 1913 are available :

										Long Tons, 2240 lb.
Zinc ore imported into :										
Germany	.	.	.	.	.	.	.	.	.	308,000
Austro-Hungary	.	.	.	.	.	.	.	.	.	50,000
Belgium	.	.	.	.	.	.	.	.	.	300,000
France	.	.	.	.	.	.	.	.	.	173,000
England	.	.	.	.	.	.	.	.	.	65,000

[To what extent the European zinc ore trade will be resumed after the war it is very difficult to predict.

THE METALLURGY OF ZINC.

In extracting zinc from its ores advantage is taken of the volatility of the metal at a bright red heat, practically all the zinc of commerce being produced by the method of distillation. The material almost exclusively employed in its production is zinc oxide, obtained by calcining the carbonate (calamine) or by roasting the sulphide (blende or sphalerite), only a comparatively small quantity being obtained from the silicates (willemite and hemimorphite).

The distillation process is dependent on the reduction of zinc oxide by carbon, or carbon monoxide, and to effect this the

* *Bulletin of the Imperial Institute (London)*, 1916, vol. xiv. pp. 44-80.

powdered oxide is mixed with coal, and exposed to a very high temperature in fireclay retorts. The carbonaceous matter must be in excess to prevent the formation of carbon dioxide, which acts as an oxidizing agent on the gaseous zinc.

The metallic zinc liberated, distils off, and is condensed in clay receivers adapted to the retorts, and a continuous stream of carbon monoxide issues from the retorts. Zinc silicates are also reduced by carbon, but require a higher temperature than the oxide. As pointed out by Gowland : * "The condensation of the gaseous zinc to fluid zinc is a matter of some difficulty, as it can only be effected within a limited range of temperature, viz. 415° to 550° C. Below 415° C. it condenses to a powder called zinc fume (or blue powder, in America)—i.e. metallic zinc in the form of powder mixed more or less with 8 to 10 per cent. of zinc oxide. If much above 550° C. it is not condensed at all. There is likewise another difficulty. If the zinc vapour is much diluted with other gases it will not condense to fluid zinc, but as zinc fume."

In preparing the ores for distillation, carbonate ores are converted to oxide by calcination in simple shaft furnaces or in reverberatory furnaces. According to Moulden,† the calcination is seldom complete, and as much even as 15 per cent. CO_2 may be left if the ores are very calcareous or magnesian.

For roasting crushed zinc blende a large variety of furnaces is used, including (1) hand-raked reverberatory furnaces, with one or two hearths, or with shelf burners; (2) mechanically raked furnaces, such as the Zellweger and Merton furnaces; and (3) muffle furnaces in use for burning blende for sulphuric acid manufacture, of which the Hegeler furnace is a modern type. Although hand-raked reverberatory furnaces with two superimposed hearths are still in use in Europe for roasting blende, they are gradually being replaced by the more economic and efficient mechanical and muffle furnaces.

The Merton furnace is said to be in successful use at two of the chief spelter works in Swansea. This is a reverberatory furnace, with three superposed hearths, and a special finishing hearth, with revolving rabbles worked by machinery.

The Hasenclever furnace is, according to Ingalls, the most

* Gowland, *Metallurgy of Non-ferrous Metals*, 1914, p. 374.

† J. C. Moulden, *Journal of the Royal Society of Arts*, 1916, vol. lxiv, p. 504.

generally used muffle furnace in Europe for roasting blende, for utilizing the gases for sulphuric acid making.

Another furnace which appears to be gaining favour in Europe is the De Spirlet. This is a multiple-hearth turret furnace, in which the hearths themselves are revolved, projecting teeth from the bottom of one hearth rabbling the ore on the hearth next below. The furnace is ingeniously designed so that it may be dismantled quickly for repairs, and it desulphurizes blende with very low fuel consumption, given as 10 per cent. or less. This furnace has been installed recently at the works of the Grasselli Chemical Co. in the United States.*

The furnaces most favoured in America for roasting blende appear to be the Hegeler and the Zellweger, the former being employed invariably when the roast gas is to be used for sulphuric acid manufacture. The improvements in the Hegeler furnace since its introduction about thirty years ago have been only in structural features and mechanical details.

Most of the new zinc-smelting plants of the United States, built in the eastern coal-fields, are designed to make sulphuric acid, and are equipped with mammoth Hegeler furnaces capable of roasting about 50 tons of ore per day.

The Zellweger furnace is a long hearth reverberatory furnace of the Brown "straight-line type," from which it differs in the form of the rabble and the supporting mechanism. Although its consumption of fuel is comparatively large it is now well established for blende roasting in Kansas and Oklahoma, where the roast gases are not utilized. The old type of Brown furnace, known as the "horse-shoe furnace," is also still in extensive use in the United States for roasting zinc blende, but according to Ingalls the later Brown "straight-line" furnace is much superior for the purpose.

For the extraction of the zinc from the calcined or roasted ore, three types of retort furnaces, viz. Belgian, Silesian, and Rhenish (Belgo-Silesian), are in use, which differ mainly in the form of retort used. The Belgian type of retort is the smallest, and the Silesian the largest. The Belgian and Silesian furnaces formerly in extensive use are gradually being replaced on the Continent and in England by the Rhenish type of furnace. The

* *Mineral Industry*, 1915, vol. xxiii. p. 797.

Belgian furnace is, however, still in very extensive use in the United States, although here also in the more recently erected plants the furnaces have been so modified that they may be classified as Rhenish.

Hand-made retorts still continue to be used in many works in England and on the Continent, but practically all the smelters in the United States are rapidly taking up the hydraulic retort-making machine for the manufacture of their retorts.

The machine in use in America has two plungers, which act upon a compact ball of well-prepared clay, pressing it into a finished retort at about 1500 lb. pressure. Such retorts are greatly superior to those made by hand, as they are denser, and on that account are more durable and less permeable by zinc vapour. They are also less readily attacked by any basic material contained in the ore. The American clays are inferior in quality to the European, but efforts are being made to rectify this difference artificially. The superior clay of the European retorts permits of the "hard driving" or distillation at a very high temperature, as practised in Germany and Belgium, but which is unknown in America. Distillation under these conditions means higher extraction of zinc, and American smelters are directing attention to the making of retorts to equal in quality those made in Germany.

With regard to the furnaces employed these are of simple construction, consisting of a narrow vertical arched chamber, in which the retorts are arranged in parallel rows, one above another, supported only at both ends in order that they may be surrounded by flame. The older furnaces have a fireplace at the bottom of the chamber, but all modern furnaces are gas-fired. This is the result of the increasing amount of roasted blende received by the smelter, which requires a higher temperature for reduction than calcined calamine. The adoption of gas-firing is now becoming very general, the gas being supplied from gas-producers built either in or near the furnaces, or entirely independent of them. In America natural gas was formerly extensively used for heating zinc distillation furnaces.

Producers of the Boetius type are used in the older furnaces in Belgium, but as the tendency in building new furnaces is to adopt the Rhenish form, the Siemens regenerative system is becoming very general in modern practice. Other producers,

however, are employed in some works. Gas-fired Rhenish furnaces, without regenerators, are in use in the Rhine provinces.

At one of the typical spelter works in Swansea, South Wales, furnaces of the Rhenish type, with gas as fuel and regenerative chambers for gas and air, are employed. The gas is generated in producers of the Siemens type.

The metallurgy of zinc involves only two operations, viz. roasting and distillation, to yield marketable metal, and is therefore simple, as compared with the metallurgy of metals such as copper involving some five operations, but the conditions of the reduction of zinc oxide to metal are, as pointed out by Sulman,* difficult and peculiar, and the reactions involved highly endothermic.

The ore charges, which are necessarily kept in the condition of coarse powder throughout the operation, are very poor conductors of heat, while to extract the metal it is necessary to continually supply heat energy by external heating of the retorts. "This imposes a maximum charge thickness of about 8 inches, a 24 hours' reduction period (from charging to recharging), the provision of small-sized retorts of specialized construction, and with only about six weeks' life, and general the handling of large bulks of raw material in very small quantities. Also it does not pay to carry the extraction of the spelter below a certain limit, the 'seconds' or residues are dumped still carrying several units of zinc." Nevertheless, viewing the present status of the practice in zinc smelting, one is impressed by the high extraction results, the low fuel consumption made possible by regenerative gas-firing, and the reduction of labour involved in the art.

While progress has been made in the metallurgy of zinc of late years, it has not been characterized by any great change in method or in the discovery of new principles, but rather by a continuous and steady increase in the productive capacity of the existing works, and by the installation of new plants. Nevertheless, the minor changes have been important, and have been directed mainly towards higher extraction results and the reduction of labour. While several new processes are being experimented with on a comparatively small scale, these are not yet sufficiently developed to judge what influence they will have on the future methods of metallurgical treatment.

* *Transactions of the Institute of Mining and Metallurgy*, vol. xx., 1910, Presidential Address.

As recently pointed out by Professor Bacon,* "The great problems at present in the metallurgy of zinc are in concentration of the ore, and in the treatment of flotation concentrates." The latter produces the troubles always experienced with fine ore; it is difficult to roast, and the distillation of it is also not simple.

Chief among the changes in zinc smelting in recent years are those in the method of firing, and the adoption of the Rhenish or intermediate type of retort, and of machine-made retorts. By the use of regenerative gas-firing and well-adapted condensers, the cost of production has been reduced and loss of metal prevented.

In direct-fired furnaces the coal consumption is about 2 tons or more per ton of ore smelted, while in modern gas-fired Belgian furnaces the consumption of coal for fuel is about 1.6 ton per ton of ore smelted. For Rhenish gas-fired furnaces the average is about 1.1 to 1.2 ton, but much necessarily depends on the quality of the coal supplied to the producer. With a view to the reduction of the cost of labour, mechanical appliances for charging and cleaning the retorts have been introduced in several European works, and more recently in American works, but they have not met with general favour.

The ore charged into the retorts generally contains about 45 to 50 per cent. of zinc. The weight of the charge varies with the size of the retorts, the Belgian retorts in the United States taking about 60 lb., plus a small quantity of by-products, exclusive of reduction material, while for Rhenish retorts in Europe it is from 75 to 90 lb. Although the Saeger charging-machine is now in regular use at the works of the National Zinc Co. at Bartlesville, Oklahoma,† where it was introduced in 1913, the common arrangement of the distillation furnaces in American works is unfavourable to the use of a charging-machine, American practice being to set the furnaces in parallel, whereas in the European practice they are commonly set in series, i.e. in a single row, thus allowing more room for manipulation. Machine-charging takes 1 hour, as compared with 3 hours for hand-charging, and the ore is charged more densely, enabling 2000 lb. more ore to be charged into the furnace.

* In his address before the American Chemical Society (Chicago, 1915).

† *Mineral Industry*, 1915, vol. xxiii. p. 796.

Two difficulties, however, attend machine-charging when applied to the excessively fine flotation concentrate now coming to the zinc smelters. This very fine ore sticks to the augers, necessitating frequent cleaning during charging, and also tends to "blow out" with considerable force, sometimes only 20 minutes after the retorts have been charged.

The method of removing the residue from the retorts generally employed in Europe, is to rake it into a pit in front of the furnace, while in America the common practice appears to be to use a long iron pipe, with water flowing from the end, which is pushed to the back of the retort, where the water is converted into steam by the heat, throwing the charge forward.

By this latter method a considerable amount of fine material is blown away, causing loss of any silver or lead contained in the residue. A retort-discharging machine has recently been patented by J. J. Simmonds, of Iola, Kansas*, which in the opinion of some distinguished American zinc metallurgists has solved the problem of mechanically discharging retort residues. Arrangements are now being made to instal the machine at three works in America. The machine consists essentially of a truck carrying a series of bars, or plungers, with sprockets at each end of the bar, over which travels an endless chain of scrapers. The machine is run up facing a tier of retorts, into which the scrapers are introduced and set in motion; the mechanical arrangements being very ingenious. The scraper chains are sprayed with water to keep them cool.

The composition of the residues naturally depends on the composition of the ores treated, but with ordinary ores the residue contains, as a rule, from 4 to 8 per cent. of zinc. With leady ores practically all the lead and silver will be found in the residues. After concentration by grinding, screening, and jigging, they are sold to lead smelters, who also value them for their iron contents, which acts as a flux. German smelters prefer zinc ores containing sufficient lead and silver to yield a residue which can be sold to lead smelters. The amount of lead admissible in the distillation process is usually considered to be limited to about 10 per cent. Moulden† has stated, however, that he has

* *Mineral Industry*, 1915, vol. xxiii, p. 796.

† *Journal of the Royal Society of Arts*, 1916, vol. lxiv, p. 507.

successfully roasted and distilled some thousands of tons of zinc ore, containing from 14 to even 20 per cent. lead. With due exercise of care and the selection of appropriate retort materials, the difficulties due to the presence of lead may be overcome to such a degree as to allow of entirely profitable commercial working. As Mr. Moulden points out, this is of far-reaching importance, as vast additional potential sources for the augmentation of spelter supply have thereby been rendered available, with the prospect of further ones now well within sight.

Careful attention is also being given in America to the gangue constituents of the ore, and the composition of the ash from the reducing agent employed with a view to reducing the amount of slagging in the retorts. Iron, lime, and manganese are objectionable impurities, although the presence of some iron is desirable. Few American smelters care to have more than $2\frac{1}{2}$ per cent. of iron, but in Europe as much as 7 to 8 per cent. is allowed.

The utilization of the unburnt coal in retort residues is another matter claiming the attention of American zinc smelters. The residue, which contains a good deal of unburnt coal, is screened, and all over $\frac{1}{4}$ -inch size, mixed with about 20 per cent. of fresh coal, and used as fuel under boilers. So far this mixture has proved serviceable at the Edgar Zinc Co., and ten boilers are now fired in this way.

In modern German and Belgian practice a 90 per cent. yield of spelter is constantly reached with roasted blende carrying 50 per cent. zinc. In the Western States of America the yield from a 40 per cent. ore is stated to be about 75 to 80 per cent., but in the newest plants efforts are being made to bring the yield up to that in Continental works. The English zinc smelters cannot claim equality with the better Continental or American practice, the yield in this country being usually nearer 85 per cent. A certain amount of conservatism and perhaps an undue regard for local tradition are partially responsible for this lower recovery. Although progress has been made, and gas-fired furnaces have almost completely replaced the older Welsh-Belgian type, a good deal remains to be done to bring English practice up to the level attained to in several Continental centres.

For example, the hydraulic pressed retort, so invariably used

abroad, has yet gained but little popularity in this country, where the heavier hand-made and more expensive article appears to be still the rule. Little attention also appears to have been given to the "briquetting" of fine ore, as opposed to the ordinary "loose charging" methods. This method, which was proposed by Sulman and Picard for dealing with Broken Hill zinc-lead concentrate, consists in briquetting the material with bituminous coal and pitch, and distilling the briquettes in an ordinary distillation furnace, when the carbonaceous residue, which acts as a filter, is found to contain most of the lead in the metallic state and is suitable for lead smelting. Very little lead is said to go over with the spelter. Notwithstanding the increased working charge of from 1s. 6d. to 2s. per ton of material briquetted, and the installation cost of the necessary plant, it is claimed the advantages are pronounced. A furnace will take from 50 to 75 per cent. more ore than when loose charged, all other distillation costs remaining the same, whilst charging and discharging operations are more rapid and cleanly.

As previously stated, English smelters are dependent on imported ores, the total importation of zinc ores in 1913 amounting to 65,000 long tons. Of this amount approximately 18,000 tons came from Australia, 14,000 tons from Italy, 9000 tons from Algeria, 6000 tons from Spain, and the remainder from other sources, including 1000 tons from Canada. American smelters treated some 855,000 short tons of ore in 1914, of which about two-thirds was blende and one-third calamine. The bulk of the calamine ore was smelted by works in the gas-fields of Kansas and Oklahoma. The smelters east of the Mississippi river make sulphuric acid, with the exception of two small concerns, and naturally use blende.

With the movement of the zinc-smelting industry to the eastward, the separation of blende roasting and zinc distillation is becoming more pronounced, as it has been for a long time in Europe. It is often good practice to roast the blende at some good centre for the distribution of the sulphuric acid, and then reship the roasted ore to a suitable point for zinc distillation. This is now being done by several large concerns.

"The loss of zinc in smelting 25 per cent. ore by the Silesian method varies between 25 and 35 per cent., that in smelting 45

to 50 per cent. ore by the Belgian and Rhenish processes being between 10 and 15 per cent. in the best operated plants; the loss in retorts by either process is about 3 per cent. per day. The combined cost of roasting and distilling one ton of ore has been estimated by Ingalls at £1 13s. 2½d. to £2 0s. 3d. for various plants in the United States and Germany."*

TREATMENT OF ZINC-BEARING COMPLEX ORES.

In no department of metallurgy has development been more rapid in recent years than in the treatment of so-called complex ores, in which zinc blende is associated with galena and other metallic sulphides. As previously stated, mechanical dressing and magnetic and flotation processes of concentration have done much towards solving the problem of complex ore treatment, as by their aid a separation can be made which will give products suitable both to the zinc and lead smelter, and also in some cases an iron sulphide product suitable for the manufacture of sulphuric acid. Following the pioneer work of Wetherill's high intensity magnetic separator, much progress has been made in magnetic separation, and many machines introduced.

Electrostatic methods for the separation, by electric repulsion, of good conductors (such as certain metallic sulphides, magnetite, and hæmatite, &c.) from poor conductors (such as silicates, carbonates, oxides, and sulphates, and including zinc blende) were first applied in practice by Blake and Mechernich, and followed by Sutton and Steele and Huff, and others. Huff discarded the electrostatic generator of the Winishurst type, and employs a dynamo-current of suitable intensity.†

The separator is thus capable of adjustment to any required strength of electrical field, and is less liable to interference from climatic conditions. In other particulars it broadly follows previous designs. Magnetic separation of blende and pyrite may be accomplished without preliminary roasting by the use of high intensity magnetic separators of the Wetherill type, the zinc mineral being lifted out of the mass. The more usual practice, however, is to give the mineral a magnetic or "flash" roast,

* See also "Costs and Profits of an up-to-date Spelter Works," by J. Gilbert, *Mining Journal*, London, 1916, vol. cxiv, pp. 480-481, 496-498; *Bulletin Imperial Institute*, 1916, vol. xiv, pp. 44-80.

† Sulman, *loc. cit.*

rendering the iron magnetic, after which it is separated from the mass by separators of the low-intensity type, such as the Dings. The limiting factor of electric separators appears to be their inability to handle fine powders, and their liability to dust trouble, unless the dust be first removed.

Flotation processes of concentration have rapidly come to the front since their introduction some ten years ago. It is to the Elmore Brothers that the honour belongs of first bringing oil-mineral processes into the region of commercial applicability and of securing the first success therein; their work focused the attention of metallurgists upon the great possibilities of these methods.

In addition to concentrate suitable for smelting, the dressing processes produce a certain amount of slime, the metallurgical treatment of which is the great problem of zinc smelters at the present time. This material is exceedingly fine, varying from 80 to less than 200 mesh, and produces the trouble that fine ore always does metallurgically, and in addition thereto some that are peculiar to the metallurgy of zinc. The loss of zinc in roasting is particularly large, and appears to be due not merely to dusting, but also to reduction and volatilization. (Ingalls.)

In view of the fact that the supply of flotation, and other concentrate and slime is bound to increase, metallurgists are making every effort to find a solution to its commercial treatment. Several methods have been proposed for treating roasted zinc-lead concentrate (Broken Hill slime) in ordinary zinc distillation furnaces for the production of a pure spelter, and a residue suitable for lead smelters. While lead is sensibly volatile in zinc vapour it may be separated therefrom to a considerable extent by the filtration of the metallic vapour through a porous medium. This fact was utilized, about twelve years ago, by Rev. E. W. Hopkins,* who used a filter of charcoal or coke, but other porous materials have since been used.

A zinc fume filter in use at Irvine, on the Firth of Clyde, consists of a fireclay tube filled with loosely packed refractory material, such as chippings of burnt fireclay, which is fitted into the back of the condenser, so that the zinc vapour passes through it. The lead is retained in the material of the filter,

* See *Journal of the Institute of Metals*, 1910, vol. iii. p. 213.

while the zinc is condensed in the condensers and contains less than 0.6 per cent. of lead.

In the "briquetting" process already referred to, the filtration takes place in the pores of the briquette itself, and the lead is found in the carbonaceous residue in the metallic state, and is suitable for lead smelting. Other methods proposed for the treatment of zinc-lead concentrate and zinc-bearing complex ores may be conveniently grouped under three heads, viz. (1) smelting processes; (2) electric smelting processes; (3) hydrometallurgical processes.

SMELTING ZINC-BEARING COMPLEX ORES.

The smelting of complex ores suffers from two main disadvantages: upon the one hand they contain too much lead for the ordinary distillation process, and on the other they contain too much zinc for lead smelting, their reduction in the blast-furnace being hindered by the excess of zinc, which requires special amounts of flux, and thus is slagged off and lost unless the slag is specially treated to recover the zinc.

In this connection reference must be made to Dr. H. Papes' method * in use at the lower Harz Mines of Oker for the treatment of the various complex ores from the Rammelsberg deposits, the main varieties of which are lead ores with 9 per cent. lead and 20 per cent. zinc, and copper ores with from 1 to 15 per cent. copper, and 1 to 20 per cent. zinc. They are treated in the ordinary way in blast-furnaces, after first subjecting the lead ore to a sulphurizing roast and removing some of the zinc by leaching.

The slags, containing from 22 to 27 per cent. of zinc oxide, are crushed to 50 mesh, and briquetted with coke dust and a binding agent. The briquettes are reduced in a continuous reverberatory furnace, where the zinc after volatilization as metal is carried off as oxide by the flue gases and is collected in chambers and bag-house plant, the better quality being sold for paint, the poorer to the zinc smelter for reduction to spelter. According to Sulman,† "Nearly 10,000 tons of metal are reported to have been thus produced, and 42,000 tons of zinc slags, besides low-grade ores, treated by this method in 1910." Sulman remarks that "zinc

* Abstract in *Mining Magazine*, 1910, vol. ii. p. 222.

† *Loc. cit.*

residues from spelter production should be amenable to similar processes, large scale trials having demonstrated the possibility of their profitable handling by such methods, when modified in certain details to suit the material."

"Under conditions of forced oxidation, such as in the blast-furnace or blowing hearth, lead is as freely volatilized in the form of oxide as is zinc, a fact which has been utilized in Germany, where the blowing of oxidized low-grade zinc-lead ores has been practised, bag-house plant being employed to collect the mixed oxide fume; this is then treated with sulphuric acid for the production of crystallized zinc sulphate, the residual lead sulphate being sold to the smelter."

The extensive manufacture of zinc white in New Jersey and Pennsylvania is a striking example of the successful treatment of a complex ore. Franklinite ore is obtained in New Jersey, and consists mainly of franklinite, willemite, zincite, and various silicates containing manganese. The dressing of the ore produces (1) a concentrate composed mainly of franklinite; (2) a concentrate consisting of franklinite, with various manganiferous silicates; and (3) a mixture of willemite and zincite. The two former are employed for the production of zinc oxide, and the last for direct spelter manufacture.

The oxide is produced by the Wetherill process, which consists in roasting the ore, then mixing with anthracite powder, and spreading it over a layer of burning anthracite on the grate of a kiln, through which a low blast from a fan is forced. The zinc distils off, and is oxidized at once by the carbon dioxide formed during the reduction of the zinc oxide, and by the air present. The gaseous products carrying the zinc oxide are passed through a cooling tower to a series of woollen bags, in a bag-house, where they are filtered and the oxide collected. The bulk of the zinc oxide of commerce is produced by this process.

The Wetherill process, somewhat modified, has been in use at Coffeyville, Kansas,* for the treatment of mixed zinc and lead ores containing not less than 30 per cent. of lead and zinc combined. The ores are mixed in such proportions that the pigment shall consist of about two-thirds zinc oxide and one-third lead sulphate and oxide. They are first roasted in M'Dougall

* Gowland, *Metallurgy*, p. 395.

furnaces, and then treated as described above, except that the fume passes first through a combustion chamber to burn off any carbonaceous matter and then passes to a sheet-iron flue about 700 feet long, which terminates in a small settling chamber, placed just before the bag-house. Here the cooled fume enters a suction fan, and is forced into the bags in the bag-house, the pigment being collected in the usual manner.

Instead of furnaces of the type used in the Wetherill process, Blum has recently proposed pots such as are used in the usual lime roasts in the Huntington-Heberlein process for lead ores. A small plant for the manufacture of zinc-white from ores is now being erected in Mexico for carrying out his proposal.

ELECTRIC SMELTING OF ZINC ORES.

The electric smelting of complex zinc ores was first attempted by the Cowles Brothers in 1883, who developed the resistance type of furnace originated by Depretz in 1849, in which a core of carbonaceous material in the charge itself carries the current in a horizontal direction.* In 1901 C. P. G. De Laval erected the first electric zinc-smelting furnace on a commercial scale, and four years later works were erected in Scandinavia to carry out his process. Since that time a considerable amount of attention has been given to electric furnaces for smelting zinc ores.

As pointed out by Professor Gowland,† "The chief drawbacks that impede the commercial success of the application of the electric furnace to the smelting of zinc ores are the cost of the current and of the electrodes, the loss of metal, and the difficulty of obtaining a fair proportion of the zinc as metal and not as oxide, which has to be re-treated."

The electric furnace is not intended to replace the retort furnaces in the smelting of zinc ores, but to be used for the treatment of ores not suitable for the distillation process, or possibly as a substitute in localities where fuel is dear but hydro-electric power easily available. Early experimental work by W. R. Ingalls, at McGill University, confirmed the opinion that, if electric smelting is to offer any advantages, the process must

* Vide "Electric Smelting of Zinc Ore," W. R. Ingalls, *Metallurgical and Chemical Engineering*, 1912, vol. x. pp. 481-485.

† Gowland, *Metallurgy*, p. 396.

be continuous, and all modern furnaces are constructed on this principle. In many of the electric furnaces now in use the energy is applied with great ingenuity and high efficiency is obtained, whilst efforts are made to reduce the electrode consumption to a minimum. The reduction in the electric furnace appears to take place more rapidly than in retort smelting, but the reaction between the carbon and carbon dioxide does not appear to occur to such an extent as in the retort. Hence the electric furnace contains an atmosphere comparatively rich in carbon dioxide, so that a larger amount of fume (blue powder) is formed than when the retort furnace is employed.

Cote and Pierron, Johnson, and others have attempted, with some success, to solve the carbon dioxide problem by such means as passing the gases through columns of incandescent carbon. But while progress has been made, the discovery of some means of avoiding oxidation of the zinc deposits, as formed under the conditions prevailing in electric smelting, is still the problem which metallurgists have to solve in connection with this method.

The continuity of operation in the electric furnace appears to imply discharging the residue as a slag that will run, and there has consequently been a tendency for inventors of electric zinc furnaces to render the charge fusible, so that fluid slags may be tapped as from cupolas. This condition, however, prohibits any great excess of carbonaceous material in the charge, and accounts for the higher percentage of carbon dioxide frequently found in continuously operated furnaces.

Among the various types of electric furnace now in use, those of De Laval, Cote and Pierron, Imbert-Fitzgerald, and Johnson may be mentioned. The first two may be selected as typical; De Laval employs the electric arc, and Cote and Pierron, slag resistance, as means for converting electric energy into heat.

The De Laval process, carried on at Trollhättan, in Sweden,* develops heat by means of the arc, current being generated from water-power at prices variously given as from 38s. to 50s. per electrical horse-power-year.† The works are equipped for 18,000 horse-power. The furnaces are of the resistance type, with one large vertical carbon electrode passing through the roof, the

* Report by F. W. Harbord on "Zinc Smelting at Trollhättan," 1911. Abstract, *Engineering and Mining Journal*, New York, 1912, p. 314.

† Sulman, *loc. cit.*

other electrode being a carbon block in the bottom of the furnace. Each furnace has a capacity of about 3 metric tons, and smelts nearly 3 tons of ore in twenty-four hours.

The complex ore is roasted to about 7 per cent. to 8 per cent. sulphur, mixed with anthracite or coke and flux, and charged through a hopper into a closed "melting" furnace, where most of the zinc and some of the lead are volatilized, and condense chiefly as crude spelter high in lead, and partly as blue powder, which has to be re-treated. The other part of the lead is reduced to metal and is tapped out with the slag. It contains a considerable proportion of the silver. Some matte is formed, and this and the slag contain some of the lead, zinc, and silver. The crude leady spelter passes to the refining furnace, where the zinc is distilled, producing, on condensation, spelter of high purity and a further quantity of zinc dust, leaving the balance of lead and silver as base bullion. Two melting furnaces supply one refining furnace. The company owning these Scandinavian works reported recently that its smelting operations have not yet proved commercially profitable; considerable progress has, however, been made, and it is hoped that things will eventually turn out well.

The Cote and Pierron process is carried on, on a small scale, at Pau, in France; experimental work was also carried on in 1914, at Ugine, in Savoy, and Quenean, in Belgium. An important feature of the process is the smelting of blende in the raw state. Whilst simplifying the metallurgy of the process, this method increases the difficulties of operation of the electric furnace. "The process * is based on the fact that iron replaces lead in lead sulphide at a comparatively low temperature, and zinc in zinc sulphide when the temperature is increased. It is claimed for the process that by its means zinc and lead can be completely separated. The furnace is circular, with sides and bottom lined with graphite, the top being a low dome of fire-brick. A carbon electrode, which can be raised or lowered, passes through an opening in the centre of the top, the other electrode, a cone of graphite, projects from the hearth. The furnace is charged through the roof, and the lead, slag, and iron sulphide are tapped through an aperture in the side. The volatilized zinc

* Gowland, *op. cit.*, p. 397.

passes through an outlet in the upper part of the furnace to the condenser, which consists of a cylindrical shaft-like chamber of fire-brick filled with coke or anthracite, and provided with a taphole at its base for the discharge of the condensed zinc."

The charge consisting of a mixture of blende, iron, and lime is introduced into the hot furnace, and the first reaction of iron on lead sulphide is effected at a relatively low temperature. The resulting lead is then tapped. The temperature is then raised and the decomposition of the zinc sulphide by the iron brought about. The zinc distils over, is condensed in the condenser, the carbon in which is kept at a red heat, to diminish, as far as possible, the formation of zinc fume. Finally, iron sulphide and the slag are run out.

In America considerable experimental work has been done with Johnson's electric furnace at Hartford, Conn., and it is stated that arrangements have been made to erect a 100-ton commercial plant at Keokuk, Iowa. This is a continuous process; with furnace of the resistance type, in which the charge carries the current. The charge is heated to about 900° C. in a continuous pre-heater before reaching the furnace. To prevent the formation of blue powder, the carbon dioxide formed in the smelting zone is rendered innocuous by passing the gases from the furnace through an electrically heated carbon filter, whereby the carbon dioxide is converted into harmless monoxide.

Electric zinc smelting has now passed the mere experimental stage and become a commercial process. It is not correct, however, to say that it has emerged altogether from the experimental stage, since it is being continually experimented upon by those interested in this method of smelting zinc ores.*

HYDRO-METALLURGICAL PROCESSES OF ZINC EXTRACTION.

Since Parnell took up the question of treating complex lead-zinc ores, at Swansea in 1881, many wet methods have been suggested and experimented with, but until recently none have met with commercial success, owing to their inability to produce metallic zinc. Unlike most metals zinc cannot be precipitated from its solutions by common metals, and if other precipitants

* Consult "Electric Furnaces as applied to Non-ferrous Metallurgy," A. Stansfield, *Journal of the Institute of Metals*, No. 1, 1916, vol. xv. p. 277.

are used, and it is obtained as oxide, this must be mixed with carbon and treated by a distillation process to obtain metallic zinc. More recently hydro-metallurgical processes have been devised in which the zinc, after having been obtained in solution, is precipitated in the metallic state by electrolysis; but while the difficulties which formerly attended the precipitation of electrolytic zinc have so far been overcome as to form the basis of recent methods, the high cost of electric power has operated against the commercial success of most of these.

However, where formerly it did not pay to leach out zinc in the form of sulphate, owing to the limited market for the salt, and the prohibitive cost of converting it into oxide, the growing demand for white pigments, free from lead, has made it possible to avoid the necessity for electrolysis by crystallizing the dissolved zinc as sulphate.

According to Sulman,* "the unit of zinc in crystalline sulphate has a considerably higher market value at present than a unit in the form of oxide for smelting purposes," zinc sulphate now being largely required for the production of "lithopone." Electrolytes of zinc chloride solution are said to be more economical in electric current than solutions of zinc sulphate, the electromotive force necessary for the decomposition of the former being less than for the latter.

The only commercially successful processes in the electro-metallurgy of zinc by indirect wet methods appear to be those of Nahnsen, Hoepfner, and Dieffenbach.† The Nahnsen process has been employed at Lipine, Silesia, from 1893 till the present day, the electrolyte used being a solution of the double sulphate of zinc and magnesium.

The Hoepfner process has been commercially successful in Germany, Austria, and England. A modification of the process is in use at the works of Brunner, Mond & Co., near Northwich, Cheshire, for the production of a fine zinc which is now made in considerable quantities for the manufacture of brass for cartridge cases and other articles requiring a highly ductile alloy.

The zinc ores are leached with waste calcium chloride in

* *Loc. cit.*

† Abstract of paper by R. Sylvany, *Journal of the Institute of Metals*, No. 2, 1914, vol. xii. p. 318.

the presence of carbon dioxide; the resulting zinc chloride solution on electrolysis gives a zinc of 99.96 per cent. purity (known as Mond Zinc), and chlorine gas, which is used in making bleaching powder.* The anodes are of lead or carbon, and the cathodes rotating discs of zinc, partly immersed in the electrolyte. The intensity of the current is 100 amperes for 10.8 square feet, with an electromotive force of 3.3 to 3.8 volts.

The Hoepfner process is in operation at Duisburg, Germany.

Two plants were also erected in 1914 at Kristiania and Balestrand (Norway) for the treatment of Broken Hill flotation concentrates.

The Dieffenbach process is applied to Westphalian iron pyrites containing 8 per cent. of zinc, which is extracted by a chloridizing roast of the crushed ore, followed by leaching with plain water. The residue, which is said to contain only 0.5 per cent. zinc, is smelted for iron, whilst the aqueous solution of zinc chloride is electrolyzed in double-compartment vats, the anode compartment being completely closed. The liberated chlorine is employed in the manufacture of bleaching powder.

The processes which are being tested in American plants are based on sulphuric acid leaching and subsequent electrolysis of the zinc solution, using lead anodes.† The well-known Anaconda Copper Co. is now completing a 25-ton plant in which flotation zinc concentrates, after a sulphate roasting, will be leached, with barely sufficient acid to extract the zinc, the resulting liquor being purified by the addition of zinc oxide. This plant when completed will, it is stated, produce some 35,000 tons of fine zinc per annum, and the venture is being followed with considerable interest.

At the Bully Hill mine (Shasta co., Cal.) the zinc sulphate liquor is precipitated with lime, and the precipitate of zinc hydroxide and calcium sulphate is suspended in the electrolyte to neutralize the acid as fast as it is formed. For the same purpose the Reed Zinc Co. (Palo Alto, Cal.), in the recovery of zinc from bag-house dust, use a spongy lead anode, which is

* "Hydro-metallurgy of Zinc in 1915," D. A. Lyon, O. C. Ralston, and J. F. Cullen, *Metallurgical and Chemical Engineering*, 1916, vol. xiv. pp. 30-32.

† "Hydrometallurgy of Zinc and Lead in 1915," D. H. Lyon, O. C. Ralston and J. F. Cullen, *Metallurgical and Chemical Engineering*, 1916, vol. xiv. pp. 30-32. Abstract, *Journal of the Society of Chemical Industry*, 1916, vol. xxiv. p. 182.

converted into sulphate. By reversing the current, sulphuric acid and lead are regenerated.

At Silverton, B.C., the ore is leached with bisulphate of soda and electrolysis carried out, with the addition of manganese sulphate. The anode becomes coated with manganese dioxide, which is redissolved and used over again.

In view of the increasing demand for electrolytic zinc, hydro-metallurgical methods of extraction are receiving renewed attention. The prospects of electrolytic zinc in relation to distillation methods of zinc extraction are very ably dealt with by W. R. Ingalls in a recent article on "Electrolytic Zinc," * to which all interested in the subject are referred.

INDUSTRIAL APPLICATIONS OF ZINC.

The zinc obtained by the distillation process in America is generally sufficiently pure for industrial purposes, but in Europe it may contain from 2.0 to 3.0 per cent. of lead, about 0.3 per cent. of iron, and small amounts of cadmium. To remove these impurities the metal is liquated in large reverberatory furnaces with sloping hearth, holding from 20 to 30 tons of metal. The refined metal is cast into slabs about 17½ in. by 8½ in. by 2½ in., weighing from 45 to 50 lb., and bearing the name of the smelting company.

The following analyses of brands of virgin spelter, by J. S. G. Primrose,† may be taken as typical :

Brand.	Lead. Per Cent.	Iron. Per Cent.	Cadmium. Per Cent.	Tin. Per Cent.
Upper Bank (English)	2.55	0.15	0.09	0.05
V.M.G. (Belgium)	0.66	0.26	nil	0.03
Vieille Montagne (Belgium)	2.00	0.04	0.07	nil
Freiberg (Saxony)	1.03	0.04	0.02	0.07
Lazyhutte (Upper Silesia)	1.12	0.02	0.017	nil
Lipine Electrolytic (Upper Silesia)	0.06	0.01	0.005	0.02

It is necessary to differentiate between spelter and fine zinc, for which latter there is a growing demand.

* W. R. Ingalls, "Electrolytic Zinc," *Engineering and Mining Journal*, March 4, 1916. See also W. R. Ingalls, "The Economics of Zinc Metallurgy," paper read before International Engineering Congress, San Francisco, 1915. Abstract, *Chemical Trade Journal*, December 11, 1915.

† *Journal of the Institute of Metals*, No. 2, 1909, vol. ii. p. 234.

The highest grades of zinc are generally prepared by the employment of pure ores, and by redistillation of ordinary spelter, but some are prepared by electrolysis.* Zinc intended for the manufacture of brass which has to undergo severe mechanical treatment, as in the manufacture of cartridge cases, should be of good grade and contain not more than 0.1 per cent. lead, and 0.05 per cent. of iron.

The galvanized iron industry probably accounts for about 60 per cent. of the world's consumption of spelter, while the manufacture of brass probably utilizes another 20 or even 25 per cent., the remaining 15 to 20 per cent. being used for conversion into sheets and for minor uses, such as the production of alloys.

Formerly the only process adopted for galvanizing was that invented by Crawford in 1837 which, as previously stated, consisted in dipping the sheets, wire, or manufactured goods into a bath of molten zinc, after preliminary treatment by "pickling" or "sand-blasting"—the method being known as "hot galvanizing." During the last few years, however, this method of obtaining a zinc coating has had formidable competitors in the deposition of zinc electrolytically, and the process known as "Sherardizing."

The advantages of the electrolytic method are mainly : (1) greater economy in the use of the metal ; (2) more complete control of the thickness of the coating on various surfaces ; and (3) its applicability to the covering of iron or steel articles which have been subjected to any special heat treatment—thus necessitating coating at the ordinary temperature of air and not at that of molten zinc. On the other hand, the surface is dull or dead, and not so pleasing in appearance as that obtained by the older method. The hot galvanizing process was responsible for the production of practically all of the 850,000 tons of galvanized sheets and wire exported from the United Kingdom in 1913.

The dross obtained at galvanizing works is frequently concentrated to about 9 per cent. iron by remelting and skimming off the purer spelter from the top, after which it is redistilled.

The enormous prices of zinc of the past year have practically brought galvanizing to a standstill, and has led to the adoption

* Consult Primrose, "Production of Pure Spelter," *loc. cit.*, pp. 231-248.

of substitutes, such as "galvanizing" with lead, which may in some cases prove to be permanent. Although it is not easy to alter the current of consumption of a world-wide commodity like galvanized sheets, the possibilities of substitutes, once the buyer is familiarized with them and finds them cheaper, is obvious. Experience to-day suggests that substitutes for zinc are having their opportunity, and will doubtless hold some of the ground they have temporarily gained.

The electro-deposition methods of "galvanizing" are now prominently to the fore and their use is increasing since, as stated above, they possess several important advantages over hot galvanizing.

Although a large number of solutions have been tried for electro-zincing, the general consensus of opinion amongst practical operators is that solutions of the sulphate, either alone or with other salts, give for general purposes the most reliable results obtained up to the present, with the minimum of trouble in working.*

In the process of dry galvanizing, known as Sherardizing, which is growing in importance, the iron and steel articles, after being thoroughly cleaned by pickling, are heated in metal drums, or boxes, in contact with zinc dust at a temperature of from 260° C. to 425° C. Partial vaporization of the zinc dust takes place, the vapour condensing on the surface of the iron articles. It is stated that the best results are obtained when the zinc dust contains 50 per cent. of metallic zinc. The inner layers of the coating are said to consist of a zinc-iron alloy. The Sherardized surface is light grey, with matte finish, but it is capable of receiving a high polish and made to resemble nickel plate. The Sherardizing process is economical, and yields a superior product. This process will doubtless receive more attention in the future than has hitherto been accorded to it.

Spelter is now being largely used for making ornamental castings, mainly what are known as slush castings, in which the metal in the mould is poured back into the ladle as soon as a thin layer next the mould has set. These castings are made as thin and light as possible to economize metal. The spelter used must be of high grade.†

* *Electro-Plating*, Barclay and Hainsworth, London, 1912, p. 312.

† G. C. Stone, *Journal of the American Institute of Metals*, 1916.

Zinc exhibits its greatest degree of ductility and malleability between 100° C. and 150° C., between which temperatures it is rolled into sheets. The metal used for this purpose must not be too high in lead and iron. According to Prost and Van de Casteele,* lead does not interfere with the rolling qualities when below 1.25 per cent., but that any increase above this is injurious. Cadmium is injurious if above 0.25 per cent., whilst arsenic and antimony are harmful from 0.02 per cent. upwards, arsenic in particular having a very hardening effect. As little as 0.01 per cent. of tin has a bad effect. Copper below 0.08 per cent. has no effect, or iron below 0.12 per cent.

In the manufacture of rolled zinc the usual practice is to cast the metal into thin plates, or ingots, which while still hot are rapidly passed through rolls until the desired thickness is attained. Most of the zinc rolling is done on the Continent, where the sheet metal is largely used for roofing. The chief rolling-mills are in Silesia and Belgium. Zinc rolling is also carried on to a limited extent in America and in this country.

Within recent years thick rolled zinc plates have been used to prevent corrosion of the plates in marine boilers. For this purpose they are drilled and bolted into position. Owing to its being highly electro-positive the zinc is first attacked by the corrosive influences, and can be renewed when necessary.

“Rolled zinc plates of specially high quality find important use in the photographic reproduction processes known as photo-zincography, and in photo-etching. Thin zinc sheeting stamped with varied ornamental designs in relief has of recent years found a very considerable use for ceilings.” †

Mention may also be made of the use of thin sheet zinc for domestic articles, such as bath-tubs, pails, toys, &c. Zinc rods find application in battery cells for electrical work. They are prepared for this purpose by casting, rolling, or extruding the metal. It is stated that the life of rods made from fine zinc is much longer than those made from ordinary spelter.

In this connection it may be noted that, as the result of a series of tests on the corrosion of commercial zincs of various compositions, E. Prost‡ arrived at the following conclusions.

* Abstract, *Journal of the Institute of Metals*, No. 2, 1913, vol. x. p. 396.

† Moudon, *loc. cit.*

‡ *Bulletin de la Société Chimique Belgique*, 1914, vol. xxviii. pp. 94-99. Abstract, *Journal of the Society of Chemical Industry*, 1914, vol. xxxiii. p. 533.

The presence in zinc of lead, cadmium, or iron in larger proportion than usually found in refined zinc leads to increased corrosion by acids. Minute quantities of arsenic, antimony, copper, or tin, especially the two former, accelerated very pronouncedly the rate of corrosion, more or less independently, of the actual percentage of impurity present.

The employment of zinc for the manufacture of seamless pipes for water supply has been advocated in recent years.* The pipes are made from pure, "hard" zinc, and have a diameter up to 80 millimetres. They can be tin-lined if required. Two pipes can be joined in the usual manner by widening the end of one and inserting the end of the other, or by covering the adjacent ends with a sleeve, and soldering. Tin solder is used, preferably with a stearine flux.

The manufacture of the pipes is simple, and their bending is easy. The pipes are as useful for water supply as lead pipes, and have the advantage of being much safer from a hygienic standpoint, as no injury has been found to arise from the traces of zinc which are dissolved by water.

Zinc is cheaper than lead for this purpose, and on account of its lightness the pipes do not require such strong wall supports as lead pipes. A pressure of 500 atmospheres is required to burst the pipes. These pipes cannot, however, be used for a hot water supply, on account of the great expansion of zinc.

In some recent tests by Rinck,† tap-water of medium hardness was sealed up in large zinc pipes with air excluded. After a year the amount of dissolved zinc was 2 to 3 milligrammes per litre. Physiological tests over a long period with water containing 7 to 8 milligrammes of zinc per litre gave no indications of injurious results.

Amongst the applications of metallic zinc must be included the use of so-called zinc dust, or blue powder, to which reference has already been made. In addition to its use in the Sherardizing process, it is now largely used as a precipitant for gold in the cyanide method of gold extraction, and is gradually replacing the zinc shavings formerly used for this purpose. Zinc dust is also

* Wittus, *Journal Gasbeleucht*, 1913, vol. lvi. pp. 936-937. Abstract, *Journal of the Society of Chemical Industry*, 1913, vol. xxxii. p. 957.

† A. Rinck, *Z. Untersuch. Nahr. Genussm.*, 1914, vol. xxviii. pp. 99-103. Abstract *Journal of the Society of Chemical Industry*, 1914, vol. xxxiii. p. 883.

largely used as a reducing agent in the dying and textile industries, and is useful as a precipitant for the removal of impurities, such as copper, antimony, &c., from electrolytic solutions. The commercial value of zinc dust depends upon its content of zinc in the metallic state, and the best grades, according to Moulden,* contain from 86 per cent. to 92 per cent. of zinc in the metallic condition. In thirteen samples of commercial zinc dust from different sources, examined by Herz,† the percentages of lead, cadmium, and zinc oxide varied between 0.15 and 5.20, 0.00 and 3.90, and 6.30 and 17.85, respectively.

Metallic zinc is also used in the Parkes process for the desilverization of argentiferous lead, and for the reduction of silver chloride produced in the refining of gold bullion.

Small percentages of zinc also enter into the composition of a large number of commercial alloys. In India it has long been used by native silversmiths for alloying with silver for the production of silver wares. Alloys used for this purpose examined by the author contained on an average 90 per cent. silver and 10 per cent. zinc.

The table given on p. 167 shows the composition of typical industrial alloys in which zinc is an important constituent.

Amongst the newer zinc alloys must be mentioned those of aluminium-zinc, which are being largely used for light castings in the automobile industry. For this purpose the alloys contain usually from 10 to 20 per cent. of zinc, with the addition of a small quantity of copper. The alloys in the aluminium-zinc series containing more than 40 per cent. appear to be of no practical value. The alloys comparatively high in aluminium are very light and strong. Those containing up to 15 per cent. of zinc are soft enough to be rolled or drawn, while beyond this amount the alloys are hard and more suitable for castings, as they are easily worked.‡

In aluminium founding zinc is largely used as an alloying metal, up to one-third the weight of the aluminium; it assists

* Moulden, *loc. cit.*

† *Transactions of the American Institute of Mining Engineers*, Sept. 1915. Abstract, *Journal of the Society of Chemical Industry*, 1915, vol. xxxiv. p. 1254.

‡ Consult "Aluminium-Zinc Alloys," Rosenbain and Archbutt. *Journal of the Institute of Metals*, No. 2, 1911. vol. vi. pp. 236-250; also O. Bauer and O. Vogel, *Mitteilungen der kaiserliches Materialprüfungsamt*, 1915, vol. xxxiii. pp. 146-198. Abstract. *Journal of the Society of Chemical Industry*, 1916, vol. xxxv. pp. 543-544.

Alloy.	Composition per Cent.						Remarks.
	Zinc.	Copper.	Tin.	Lead.	Nickel.	Antimony.	Aluminum.
<i>Anti-friction Metals—</i>							
Anti-friction metal	85.0	5.0	...	...	...	10.0	...
Babbitts metal (so called)	69.0	4.0	19.0	5.0	...	3.0	...
Bearing metal	8.0	82.0	10.0	...	...	...	...
" " hard	2.0	82.0	16.0	...	...	...	...
" " medium hard	6.0	67.5	21.5	...	...	...	...
Lumen bearing metal	20.0	76.0	3.0	1.0	...	...	...
Special " "	85.0	10.0	...	...	...	...	5.0
Vaucher's alloy	82.0	12.0	...	...	...	2.5	6.0
<i>rarees—</i>	75.0	...	18.0	4.5	...	...	...
Aluminum brass	38.0	60.0	...	...	...	...	2.0
Best yellow brass	30.0	70.0	...	...	...	...	...
Brass	5.0	94.5	...	...	...	...	0.5
" " to be machined	29.0	70.0	1.0	...	...	...	...
Cast brass (so called), very variable.	38.0	60.0	...	2.0	...	...	...
Naval brass	37.0	62.0	1.0	...	...	...	...
Ordinary brass	33.3	66.6	...	...	...	...	...
Atch's metal	38.0	60.0	...	...	...	...	...
Delta metal (average composition)	36.0	60.0	2.0	1.0	...	...	2.0
Muntz metal	40.0	60.0	...	...	...	...	1.0
Parson's white "brass"	30.0	5.0	65.0	...	...	...	...
Sterro metal	55.5	42.0	...	...	...	...	2.5
Brazing solder	50.0	50.0	...	...	...	...	...
<i>Bronzes—</i>							
Coinage bronze (British)	1.0	95.0	4.0	...	...	...	...
Gun, metal	2.0	88.0	10.0	...	...	...	...
" "	1.0	86.0	13.0	...	...	...	...
Manganese bronze	42.0	54.5	1.5	...	...	...	0.5
"German Silvers" (so called)—							
Firsts	28.0	56.0	...	...	16.0	...	...
Seconds	24.0	62.0	...	...	14.0	...	...
Thirds	32.0	56.0	...	...	12.0	...	...
Fourths	35.0	55.0	...	...	10.0	...	...
Fifths	36.0	57.0	...	...	7.0	...	...
<i>Miscellaneous—</i>							
Admiralty metal	28.5	1.5	70.0	...	...	...	...
Ashberry metal	1.0	2.0	80.0	...	...	14.0	...
Motor alloy	10.0	2.0	...	...	...	...	...
White button metal	80.0	20.0	...	...	...	...	88.0

For work under water.
Other metals 3 per cent.
Light alloy for motor-car work.

in the production of sound castings, and incidentally raises the tenacity very materially.

In the opinion of a recent writer,* the suggestion that the aluminium-zinc alloys are unreliable and likely to break down through disintegration, has not been proved to be a serious difficulty. The writer further points out how essential it is to control the casting temperature of such alloys. From tests made by Bancroft,† it appears that with the addition of zinc to aluminium the tensile strength gradually rises to 15·5 tons per square inch at 30·0 per cent. zinc. There is then a steady fall to 11·0 tons, with 96 per cent. zinc, and with further additions the decrease in strength is very rapid. The ductility of aluminium is lowered by zinc, falling to 5·0 per cent., when 10 per cent. of zinc is present. All alloys containing more than 10 per cent. of zinc give approximately the same ductility, namely, about 2·5 per cent.

The industrial importance of the aluminium-zinc alloys is gradually being more fully recognized.

With regard to zinc in alloys for bearings, it may be stated that at least 75 per cent. of the car journal bearings in use on United States railways contain upwards of 2 per cent. of zinc. In a recent investigation on the effect of zinc on the mechanical properties of copper-tin-lead bearing alloys, Clamer ‡ concluded that alloys containing not less than 65 per cent. of copper, and approximately 5 per cent. of tin, up to 20 per cent. of lead, and up to 5 per cent. of zinc, should be satisfactory for all classes of car journal bearings. With an increase in the amount of lead, the zinc content should be correspondingly diminished.

In the author's opinion, the extension of the use of zinc in the future will be dependent in no small degree on the discovery of new alloys suitable for industrial purposes. Much work yet remains to be done in studying the influence of the addition of metals such as nickel, cobalt, and chromium on commercial zinc alloys. Thus research has shown that the properties of certain brasses are considerably improved by the addition of small amounts of nickel.

* *Foundry Trade Journal*, August, 1914.

† Paper read before the American Brassfounders' Association, 1910. Abstract, *Mechanical Engineering*, No. 634, vol. xxv. p. 329.

‡ G. H. Clamer, American Institute of Metals, September, 1915. Abstract, *Journal of the Society of Chemical Industry*, 1915, vol. xxxiv. p. 1098.

Of the various compounds of zinc of commercial value, zinc oxide is by far the most important. It is largely used as a pigment, under the name of zinc-white, and is valued for its lack of discoloration, as it is not blackened by sulphuretted hydrogen like white lead, for which it is a substitute. Although it lacks the body and opacity of white lead, and is non-poisonous, it has good covering power. The zinc oxide of commerce is frequently adulterated with barium sulphate, sometimes to a very considerable extent. Considerable quantities of zinc oxide are also used in rubber and linoleum manufactures, and in medicine it appears in zinc ointment. The bulk of the zinc oxide of commerce is made direct from zinc ores in America, as previously described, while it is also prepared in Europe by the combustion of metallic zinc.

Other compounds of zinc of industrial importance are zinc sulphate, or white vitriol, and zinc chloride. Both these are prepared from zinc scrap by dissolving it in sulphuric acid and hydrochloric acid respectively, and crystallizing out the resulting salt. Zinc sulphate is used in medicine and in the textile industries as a mordant, and in the manufacture of glue, where it acts as a clarifying agent and preservative. Within recent years zinc sulphate has found its greatest application in the manufacture of lithopone, used as a pigment as a substitute for the more costly zinc oxide.

Lithopone, which is a mixture of zinc sulphide and barium sulphate produced by combined precipitation using barium sulphide and zinc sulphate, is a stable pigment employed largely in the manufacture of enamel paints. Zinc chloride is mainly used as a preservative for timber, and in the textile industry. It is also used in surgery as a caustic and as an antiseptic.

FUTURE OF THE ZINC INDUSTRY.

Before the war spelter reduction plants were in excess of the world's requirements, as is evidenced by the fact that a Convention limiting output has been in force for some considerable time.* The effect of the war on the spelter market has, however, been most pronounced, owing to the fact that the greatest zinc-producing centres of the world, outside the United States, are located in the

* *Mineral Industry*, 1914, vol. xxiii. p. 764.

war zone of Europe. The European smelters have either been forced to suspend operations, or if able to operate, their product has not been able to reach the outside world. This condition of things not unnaturally resulted in a shortage of spelter and consequent rise in price, the selling price of the metal having appreciated to more than five times its pre-war figure, while for a short period the price was carried as high as £120. The reasons for this totally unprecedented advance need not be entered into here, but obviously such an alteration in the value of any metal raises serious considerations as to its uses as well as its sources of supply, and also the possibilities of substitutes, as already pointed out.

The cutting off of the European supplies of spelter resulted in an extra call being made upon American supplies, and the response made has considerably eased the situation.

Very great efforts have been made in the United States to take advantage of the unique conditions now existing as the result of the war. In 1914 there were thirty-three zinc-smelting plants in the United States, but many of these have since been enlarged and new works are being erected or have been completed. The total capacity of the American plants will thus be brought up to something like 650,000 tons per annum, or just double the output of 1913, which amounted to 320,000 metric tons, or 32.1 per cent. of the world's total spelter output. Every effort is being made to put the new plants into commission as early as possible. The United States Steel Corporation in particular is erecting two plants, one at Donora, part of which has recently been commissioned, and the other at Gary, Indiana, with a combined capacity of some 70,000 tons.

In view of the large ore reserves in America, there is no reason to suppose that there will be any failure to realize the expected output through smelting plant being in excess of the capacity of the mines.

The possible demand for spelter in America has been given by C. F. Siebenthal, of the U.S. Survey, as 594,000 short tons per annum. The excess of production over this (some 56,000 tons) will be available for export, with the possibility of trade in galvanized sheets, wire, and other products with the Southern Continents and Asia, a field not hitherto touched by America.

With regard to the future of the German and Belgian spelter industries, it must be borne in mind that both these countries have in the past relied very largely on foreign ore supplies to maintain their large outputs of metal. Under these conditions the chief obstacle to these continental industries regaining the position they occupied before the war will most probably be a shortage of ore.

But while the importation of ore from Australia and other countries into Germany is now stopped, Germany has supplies of ore available in Silesia, Hungary, Carinthia, and Tyrol. These deposits have, however, been worked for more than three centuries, and are partially exhausted, and the supply of ore, even when the mines are worked to their full capacity, will doubtless be short of that required to maintain the large output of spelter for which Germany has hitherto been responsible.

It must not, however, be overlooked that Germany has considerable mining interests in the East, and attention has already been drawn to her increasingly large shipments of zinc concentrates from China. This source of supply is doubtless capable of considerable extension, and Germany will not fail to develop the ore trade in this direction as soon as the opportunity occurs.

It is reported that the Germans are keeping together the skilled labour of the Belgian zinc works, and that they are assisting in the running of some of the smelters of Belgium. Since, however, the available supplies of ore for both Germany and Belgian spelter works is very limited at present, it is doubtful whether the output is very large.

The future of the Belgian zinc industry is very uncertain, as there is some doubt as to the fate of the works when the enemy are obliged to evacuate the country. Hitherto the Belgian industry has been largely controlled by German influence, a condition that is not likely to continue after the war. The imports of foreign zinc ores by Belgium will no doubt be renewed in the future and every effort made to bring the industry up to its former high production. For some time, however, the total output of Germany and Belgium will probably only be sufficient to satisfy home consumption.

Although American manufacturers are taking full advantage

of the present position, and there will be considerable difficulty in meeting their competition in future, this would appear to be a very favourable opportunity to expand the spelter industry of this country, so that it may take a larger share in contributing to the world's supply of zinc.

Hitherto Great Britain has been in the anomalous position of having to purchase spelter from oversea countries (at fabulous prices since the war began) while there are abundant supplies of zinc ore within the British Empire, but inadequate smelting plant for its treatment.

As much has been written recently on the British spelter industry, and the treatment of Broken Hill concentrates in Germany, it may be well to state, on the authority of Moulden,* that although the Germans obtained control of a large proportion of the huge output of Australian zinc concentrates, they did not treat the concentrates except in relatively minor quantities.

Moulden points out "that they utilized this control to make money, in which they were most successful, passing the major part of the concentrates on to the Belgian works for smelting. Of the total Australian output Belgium smelted at least 75 per cent., and Germany only 14 per cent. They had placed themselves in a position to force this on the Belgian works by acquiring at the outset a controlling interest in a number of them."

As previously stated, the European spelter market was, until August 1914, controlled by the Spelter Convention, which was largely dominated by Teutonic influence, and regulated practically the whole of the metal output and the price.

It is gratifying to know that schemes are now under consideration for the expansion of the zinc-smelting plants within the Empire to deal with domestic zinc ores.

Now that the Zinc Corporation and the British Broken Hill companies have been released by the Board of Trade from their contracts with the German groups, steps are being taken to erect the necessary smelting plants both in this country and in Australia. An agreement has been reached between the spelter producers in this country and the Ministry of Munitions on the subject of new works, with a view to increasing British spelter production. The producing companies are to be allowed to deduct from their

* *Loc. cit.*, p. 528.

excess profits the difference between the cost of new production during the war and before the war; they are also to receive from the Ministry of Munitions a "reward" for extending their works, in that they will be allowed to deduct from their excess profits, before taxation, 50 per cent. of the pre-war cost of construction. As a result of this arrangement at least two companies, the Swansea Vale Spelter Smelting Works, and the Sulphide Corporation works at Seaton Carew, have arranged to double their smelting capacity, and others will probably follow. A scheme, Imperial in its scope and objects, has also been drawn up and is under consideration. This provides not only for preferential treatment of the Empire's zinc ores, but also allots a fair share of the raw material to our Allies, France and Belgium.

It is pointed out that the proposal to increase the production of spelter in the United Kingdom with the safeguard of a bonus, would mean that Australia would assure all the supplies needed of the raw material, and that the Imperial Government by the bonus system would insure them against the risk of any possible loss. Attention is also being directed to the possibility of developing the sources of zinc ore in the British Isles, which with the application of modern methods of dressing, aided by adequate capital, may yet be profitably worked. The increase of spelter production in Australia is also being considered, and steps have been taken to reconstruct and enlarge the smelting works at Port Pirie, so that the capacity will be brought up to deal with the smelting of nearly 4000 tons of zinc concentrate per week. The plant now (1916) comprises 10 gas-fired furnaces each containing 2 tiers of Rhenish retorts back to back, with three rows of 24 retorts in each tier, i.e., a total of 1440 retorts. The charge consists of 10,000 lb. of washed concentrate, 3000 lb. of coke, and 1500 lb. of coal, and the retorts are heated slowly to 1325° – 1350° C. About 80 to 85 per cent. of the total zinc present is recovered as spelter and blue power (zinc dust), the latter containing about 92 per cent. zinc and amounting to 12 per cent. of the total zinc obtained. The crude spelter contains 2 to 3 per cent. lead and is refined to a 99 per cent. product by liquation.*

Canada is also giving attention to the possibilities of treating domestic zinc ores, Mr. J. C. Nettle of Swansea having recently

* *Bulletin of the Imperial Institute*, 1916, vol. xiv, pp 44–80.

(in 1914) reported that the ores, although somewhat refractory, could be treated by ordinary distillation methods. Zinc is being extracted from ore by leaching and electrolysis at Silverton, British Columbia, and a new zinc smelting plant is being erected at Trail, B.C.

To encourage the erection of zinc smelting and extraction plants, the Canadian Government have agreed to grant bounties on a sliding scale, not exceeding 2 cents (1*d.*) per lb., on the production of zinc in Canada from Canadian ores when the standard price in London (England) falls below £33 per ton of 2000 lb. Such zinc must not contain more than 2 per cent. of impurities.*

It is to be hoped that the efforts that are now being made to extend the British zinc industry will prove to be successful, and that the industry will take a position worthy of the metallurgical standing of the Mother Country of the Greatest Empire in the world.

The distinguished metallurgist, Dr. John Percy, pointed out half a century ago that "in proportion to the success with which the metallurgic art is practised in this country will the interests of the whole population, directly or indirectly, in no inconsiderable degree be promoted." † This is equally true to-day, not only of this country but of the Empire, and it is a truth that we shall do well to remember.

* *Board of Trade Journal*, September 9, 1915.

† Inaugural lecture to students of the Royal School of Mines, London, 1851.

DISCUSSION.

The PRESIDENT said that although there was not a very large attendance at the meeting there were members present who possessed sufficient expert knowledge to tackle the subject raised in Mr. Smith's paper. The question of zinc production was one of great national importance, and it would be very gratifying if the Institute of Metals could make some genuine contribution to the subject as it stood at the present day. As far as he had been able to study the paper, he had come to the conclusion that it formed a very admirable introduction to the subject as a whole.

Mr. H. K. PICARD (London), in opening the discussion, said that the subject with which the Author had dealt was a large one, and he was to be congratulated on having given such a complete survey of the zinc industry within the limits of the paper. Any one branch of the subject could supply material for a paper of the length of that presented, and he assumed that the chief difficulty with which the Author had been faced was in knowing what to leave out.

He noticed that the paper was written twelve months ago, and for that reason it was perhaps not quite so up-to-date as it would have been had it been revised more recently. That criticism applied more particularly to the flotation treatment of ores, a subject with which he was familiar. On page 147 the Author quoted Professor Bacon as saying "The great problems at present in the metallurgy of zinc are in concentration of the ore, and in the treatment of flotation concentrates," a remark made at Chicago in 1915. He (the speaker) did not agree with those views; on the contrary, in his opinion, the smallest problem connected with the metallurgy of zinc was that of the concentration of the ore. Flotation had settled that once and for all. In support of this it was only necessary to refer to the fact that in pre-war times Broken Hill produced sufficient flotation concentrates to satisfy at least one-quarter of the zinc requirements of the world.

The Author stated on page 152, "In addition to concentrate suitable for smelting, the flotation processes produce a certain amount of slime, the metallurgical treatment of which is the great problem of zinc smelters at the present time." He did not think that expression was correct; the flotation process did not produce slime. It was capable of concentrating slime, and therein perhaps lay its chief virtue. In ordinary concentration it was necessary to remove the slimes from the crushed ore before concentrating the sands, the former being treated separately with, at best, indifferent results. The flotation process possessed the advantage that it would take the mixed sand and slime and concentrate them together, with the result that the net recovery of metal in the form of concentrate was very much higher than by any other known system of concentration. He did not think he would be wrong in saying

that any zinc blende ore that was amenable to flotation concentration would yield something like 95 per cent. of its value in the form of a high-grade concentrate suitable for smelting. The fact that the continental smelters had been able to deal with the large quantities of concentrates produced in Australia, all of which contained a certain amount of slimes, showed that this class of material could be smelted without difficulty.

On the same page the Author made the statement "metallurgists are making every effort to find a solution to its commercial treatment." On the contrary they were not making any such effort, this material having been successfully treated for a considerable time both by the Germans and by United States smelters.

The Author stated on page 148 that "German smelters prefer zinc ores containing sufficient lead and silver to yield a residue which can be sold to lead smelters." In his opinion that view was incorrect. The Australian zinc blende concentrates which the Germans had been treating carried a certain amount of silver, and to recover that there must be some lead present. The flotation process could produce a concentrate almost free from lead if desired, but the German smelters called for a product containing not less than 8 per cent. of lead, which was required for collecting the silver. If it were merely a question of smelting silver-free zinc ore no zinc smelter would "prefer" to have material containing lead.

Passing to another point, the Author quoted Mr. Moulden, a recognized authority on zinc smelting, to the effect that he could smelt zinc ores containing as much as 20 per cent. of lead without any difficulty. He could confirm that because some years ago he was connected with the briquetting process referred to in the paper, for the treatment of complex zinc-lead ores. In that case several thousands of tons of zinc-lead slime containing on the average 25 per cent. of zinc and 25 per cent. of lead were treated by the briquetting process, and no trouble was experienced due to the presence of lead. That was confirmed in an interesting article by Mr. Theodore Hoover in the "Engineering and Mining Journal" of August 13, 1910. Mr. Hoover there reported the treatment of some 600 tons of ore containing 24.38 per cent. of lead, and stated that by briquetting the ore he introduced 33 per cent. more ore into the retort than was possible by loose charging. Moreover, although the ore contained so much lead, the destruction of the retorts was less than in the case of smelting ordinary zinc ores containing practically no lead. The briquetting operations that he had just referred to were not commercially successful. They were carried out on rather a small scale about the years 1900-1 when the price of metals was extremely low, and in view of the cost of the carriage of the ore there was a very small margin of profit; but the operations were considered sufficiently satisfactory by independent observers to justify the erection of a plant in Australia for carrying out the process. That again did not succeed very well. It

was the first zinc plant ever erected in Australia, and the numerous difficulties which arose in connection with the establishment of a new industry manifested themselves. In course of time those operations were stopped, at a period almost coincident with the development of flotation, and as this process was able to supply zinc concentrates more or less free from lead the question of treating a mixed product no longer arose.

It might be of interest to state that the Sulphide Corporation Ltd., were the firm which had the enterprise not only to erect the first zinc furnaces in Australia but to introduce and develop at Broken Hill the flotation process, which had since been extensively adopted in all parts of the world, for the treatment of ores of zinc, lead, copper, gold, and silver. The industry as a whole was indebted to the Sulphide Corporation for their work in the initial stages of development of a great metallurgical industry. Before leaving the question of the briquetting process he noticed that mention was made in the paper of the limits of iron contents which zinc smelters insisted on in their ores. If briquetting was adopted it did not matter how much iron was present. In the works to which he had referred an American ore containing 20 per cent. of iron was smelted without difficulty, whilst ores containing fluorspar and excessive amounts of lime could be successfully treated by this process, to which considerable attention had been paid recently in the United States.

Passing to the more general question connected with the installation of further plants for the purpose of dealing with the minerals produced within the British Empire, he thought the Author had laid down the essential conditions in a few words on page 127: "This localization of the zinc industry is due to the necessity for cheap fuel, the occurrence of fireclay required for the retorts, and the necessity for skilled labour, while the climatic conditions must be suitable for the trying conditions of the workers." That summed up the whole position. As to the development of the industry in Australia he did not know how that country was situated with regard to clay, but he believed that sources of suitable material were now available. When he was in Australia at least half the clay for the retorts had to be imported from England. Although two clays might show the same analysis it did not follow that each was equally good for the manufacture of a zinc retort. The Australian summer climate also constituted a definite difficulty, zinc working even in temperate countries being severe upon the men.

The Author had referred in his paper to wet methods for the treatment of zinc ores, but he had not, from the speaker's point of view, sufficiently discussed this aspect. Some persons in Government circles held the opinion, he believed, that wet processes were more or less unreliable, particularly in reference to the production of electrolytic zinc; personally he did not share this opinion. Electrolysis of zinc sulphate solutions, admittedly, was not altogether an easy matter;

thus it was necessary in the first instance to ensure that the solutions were obtained in a state of high purity, but that was not beyond the skill of technical chemists. The strengths of the solution in zinc and acid were important factors, but these were now well known. Lasczynski, he believed, was among the first to adopt the method of bagging the anodes, thus removing certain difficulties arising during electrolysis; good results were reported of this process from Austria and Sweden. The Author referred to the electrolytic work at Anaconda, and rather suggested that it was still in an experimental stage. The case was now different; he believed he was correct in stating that from 1000 to 2000 tons of ore a day were now being treated by the flotation process, and a large proportion of the concentrates produced were being treated electrolytically.

So far as the future of the zinc industry was concerned, he was no better prophet than the Author, and he would therefore not like to express any opinion in regard to the treatment of the vast sources of minerals existing within the Empire. He could only hope that, with the assistance of the Government and private enterprise, they would hold their own. There was perhaps one point that it might be useful to mention. He thought co-operation and exchange of information was rather lacking in zinc metallurgy. That was not good for the industry. At one time he paid a visit to several copper smelters in America where he was impressed with the cordial nature of his reception. The managers took him over their works, and freely discussed the operations. This principle of interchange of information was, he thought, the right one. He did not know how far that applied to the zinc industry in that country, as he had not had the occasion to test it. He admitted that there was difficulty in securing this co-operation. A valuable improvement was oftentimes only secured to the inventor after he had established it by lengthy and expensive law suits. This condition naturally tended towards maintaining secrecy, to the benefit perhaps of the individual, but to the loss of the industry as a whole. Some change in the Patent Laws might possibly help to remove this condition, though it was difficult to suggest a practical remedy which would ensure to the inventor his fair reward whilst giving the benefit of his discovery to the industry.

Finally he congratulated the Institute on securing such a valuable contribution to their Journal.

Mr. ROBERT MOND (Sevenoaks) congratulated the Author on the symmetry with which he had dealt with such a very large subject. All the members were aware of the great difficulty that existed when they endeavoured to sum up a large industry like the zinc industry, the tendency being to expand those portions which were their own particular hobby and unduly to compress the balance. From beginning to end the Author had managed to avoid that fault, and had devoted the right amount of space to the different parts of the paper.

He (Mr. Mond) was not a member of the Institute nor was he a zinc smelter, but years ago he did some zinc mining in North Wales, and he had followed up the flotation and all the different concentration processes which had been adopted with the endeavour to extract as much lead and zinc as possible from extremely poor ores. He had been engaged in working out the hydro-metallurgical processes for obtaining zinc, and in connection with these there were many difficulties which had to be overcome. That represented a very large amount of hard work, because the difficulties met with were of an entirely unexpected nature and the reasons for which it was difficult to discover. The original idea of his father, when he first took an interest in the electrolysis of zinc, was that he saw in it a method of obtaining either chlorine or zinc as a by-product of the manufacture.

In Germany and in Silesia large quantities of zinciferous iron ores existed and the zinc fumes which came out of the blast furnaces were a great nuisance, so that naturally led to endeavours being made to deal with the problem. The iron ores contained from 6 to 10 per cent. of zinc, and the attempts which were made to get the zinc into solution, turning it into zinc sulphate and then recovering the zinc, led chemists like Dr. Goldschmidt of Frankfurt and a number of other chemists to tackle the subject with the object of discovering whether the zinc in the iron ores could not be removed. They found that by turning the zinc into zinc sulphate, treating it with sodium chloride so as to obtain zinc chloride, and freezing out the sodium sulphate, a zinc chloride was obtained either in a solid state, such as Dr. Goldschmidt was working at, or electrolyzed such as Dr. Hoepfner tried to produce. Dr. Mond tried to obtain chloride from zinc ores by the process of introducing carbonic acid into a solution of calcium chloride, with zinc oxide in suspension in it, and thus obtaining the zinc in the shape of zinc chloride, and subsequently electrolyzing it. Those processes involved immense difficulties, one of the greatest being to get the zinc into solution at all or to get a reasonable amount of the zinc dissolved. That depended on a number of different things, for instance, the state of chemical combination in which the zinc was found in the ores. In calamine the zinc was largely present as a silicate. As a result the zinc would not go into solution and the metal losses were large. Having successfully got the zinc into solution as chloride, the question arose how to get it out, and it took years to solve the problem. When they tried to work with electrodes, it was found that the chlorine penetrating into the liquors dissolved the zinc as fast as it was put in. If the zinc was deposited on iron sheets, local action was set up. That was met to a large extent by revolving the cathode plates, thus avoiding polarization. A number of other difficulties had to be met. In those days Acheson had not worked out his beautiful method of making carbon in high temperature furnaces; and the carbons obtainable disintegrated very rapidly. In their first experiments they started with gas coke, but if it was too dense it was very

difficult to make any good contact and the internal resistance of the anode increased rapidly. All that took a very long time. Another great difficulty occurred whenever local action occurred, which was very easily brought about, because they tried to work with the highest current density practicable. A further difficulty was to get the right kind of material for the diaphragms for keeping the chlorine in, and guiding it in the correct way. The statements he had read with regard to the use of chlorine gas at the Front had very vividly called to his mind the number of times he had been "gassed" when trying to find leaks in the cells and seal them up again. If an endeavour were made to get the chlorine off by means of a vacuum then too much air was drawn in and the chlorine became too dilute. One difficulty or another always had to be faced. It was necessary also to make the solutions extremely pure. They had to make them so pure that it was necessary to devise new analytical methods in order to discover the traces of those impurities which were found to be of importance. After prolonged research, extending over about ten years, carried out in an earnest manner by a series of different assistants and chemists, all working together in unity, they succeeded in getting the process to work more or less satisfactorily, and it had now arrived at such a state that unpleasant surprises no longer occurred. One of the most remarkable things about the process was that the chemist went away quite happy from the works in the evening, and he was sure to be called up by the foreman in the middle of the night with the message that everything was wrong. As long as the process was in that condition it was not commercial. Dr. Mond also tried to work out another process which, from an electro-chemical point of view, was still a great difficulty, viz. to obtain zinc from zincate of soda. Instead of decomposing sodium amalgam with water, as was done in the ordinary mercury cell, it was decomposed with caustic soda in which zinc oxide had been suspended or dissolved, and it was then possible to completely prevent the production of hydrogen and obtain a deposit of metallic zinc. The difficulty was to obtain a deposit which was not spongy. Again after a large number of years' work, success was achieved. One of the great difficulties was to prevent the zinc getting into the mercury. They managed to get good metallic zinc from the zincate solution, which everybody who had tried to do so up to that time had dismally failed to accomplish, and that was one practical result obtained after a large number of years' hard work. He was afraid he had not been able to obtain much information about the zinc sulphate processes which were now being used in America; they had been introduced since his last visit two or three years ago, and he had not had time recently to go to America to see what was being done.

He did not see any reason, however, why the Americans should not be successful in manufacturing zinc at a price. One of the reasons which kept the English zinc industry back for a long time was the

remarkably low price at which zinc was sold. He believed he was safe in assuming that the reason the price was so low was the remarkably rich and cheap zinc ores which were found in the Toppling district, from which it was possible to produce zinc at a very low price. He remembered some fifteen or sixteen years ago discussing with Mr. Chalmers, of Fraser and Chalmers, the metal losses in zinc produced from dressing plants and being told that the total metal losses were usually slightly higher than the average metal contained in the metal ores he was trying to dress in North Wales. The fact was occasionally forgotten that, however economical a smelting process might be, the main price of any metal really consisted of the cost of the ore and in getting that ore to the smelting plant. A particular process might be slightly more economical or a great deal more economical than another, but if the cost of the ore were considerably cheaper the economy of the process did not count. That was what had kept back the development of the industry in this country. The fact that the ores were right away in the centre of America, from which they could not be economically brought to this country, prevented English manufacturers from using them in order to make cheap zinc, and they were therefore handicapped in not having cheap ores to deal with.

The very large deposits of mixed ores which formed the mineral riches of Australia involved a complicated dressing problem which had taken a long time to solve; and it was only the successful solution both of the magnetic separator and of the flotation processes (which latter was not a simple matter in itself, and which owed a great deal of its success to the large amount of work done in regard to colloidal substances and their behaviour) which had enabled the manufacturers of this country properly to treat them. He remembered some twelve years ago inspecting the original plant put up at some copper mines near Dolgelly. At that time it was not a plant which led him to hope for a successful outcome. The original plant did not produce any results of technical value, except in pointing to the direction in which further progress might be expected, and he thought he was right in saying it had taken at least ten or fifteen years of experimenting in different directions before a process was evolved which succeeded in solving the problem of dealing with the ores. As soon as the problem was solved, the local conditions had to be studied and worked out. He had been working out the local conditions for some ore in Canada, and knew the amount of detailed and technical work that had to be done to hit off exactly the right conditions for the particular problem being dealt with.

He spoke subject to correction, but he believed it was to a large extent to the credit of the German firms who made contracts in Australia that the flotation process was introduced and worked out. It was certainly the fact that after they got the process to work they got the contracts. There was no reason why the process should not have been worked out in this country, but in all such things it was generally found

that brains had no nationality, and that good brains were few and far between. We were very pleased that they were there in order that we might make use of them. As far as he could see the future of the industry would be a very remarkable one. It was quite probable that the correct thing to do with the zinc in Australia was very much the same as the French had done with the nickel ores of New Caledonia—to establish smelters at both ends of a line of steamers so as to provide freight both ways. In a case where large distances had to be traversed in order to bring the raw material together to a common focus, a point was arrived at where, if there was a serious disproportion in volume or in weight of the products which had to be carried backwards and forwards, it was necessary to make up freight, and one of the ways of doing that was to put up works at each end so that some products could be made at one place and some at the other, and thus provide freight for the line of steamers employed for doing so. It was quite possible that our relation with Australian smelters would work out in that way. It would depend upon the extent to which we sent goods from here to there, for instance, Canadian pit props and similar articles. He was not sufficiently aware of the articles which Australia would require to fetch from this country in order to bring here their mixed ores besides their spelter.

He thought the industry in this country had also suffered from the fact that only now, at the last moment, was it beginning to adopt proper methods for collecting the sulphuric acid fumes which had been a great deal of nuisance during a considerable number of years. He was pleased to see that at last we were beginning to condense some of the fumes and turn them into a very much better substance. Where zinc works had been put up, for instance at Landore, the immensely destructive action of the zinc fumes on the surrounding country could be seen. He thought it was a fact that the zinc smelters had not produced sulphuric acid, and that was one of the reasons why, if anybody wanted to start a new works, the people in the neighbourhood complained. Not long ago some works started in Cheshire had to be closed on account of the acid fumes that escaped.

One factor which would affect the zinc problem was how far America would be able to deal with its own home consumption. America had been using a very large amount of her enormous war profits in creating a tremendous production, and who was going to consume that enormous production remained to be seen. Whether or not it would have to swallow its young like Father Chronos, was a matter that rested in the hands of the gods.

Mr. H. K. PICARD desired to say, in reference to the remarks that Mr. Mond had just made, that the Germans had nothing whatever to do with the technical development of the flotation process from first to last. He was able to say that emphatically because he had been connected with it from its inception. It was an invention that was

made and developed in all its details by British metallurgists, and it was only after they had produced the concentrate that arrangements were made with German smelters to treat them.

Professor T. TURNER, M.Sc., Vice-President, said that the difficulty he experienced in discussing the paper was that, as had previously been pointed out, it covered such a wide field, and any one branch of which would well repay a whole evening's discussion. For example, in connection with the ordinary dry method of obtaining zinc by distillation, one of the things that struck him very much in visiting the Belgian works some years ago was the question of the production of the retorts, to which reference was made in the paper. He referred not only to the mechanical appliances for pressing the crucibles, which had been to some extent adopted since in South Wales, but also the examination and the testing of the clay. Broadly speaking we were in England a long way behind the position occupied by the Belgians, and also the Germans, in the testing of refractory materials for such purposes as the manufacture of fire bricks, for retorts for gas making, and for retorts for zinc manufacture. It was also true that in America refractory materials were being examined by methods which were not nearly so fully used in this country—he referred to the careful classification of the materials following on the lines of Schöne, and including the microscopic examination of the particles. These were so sized and separated that it was possible to recognize the different mineral constituents in the fine clays and the coarser sandy particles. In that way it was possible to classify clay. He thought it was Mr. Picard who had stated that it was found that two clays of the same chemical composition gave very different results. That was now a well recognized fact. It was well established that it was possible to have two clays of precisely the same ultimate chemical composition, and yet on account of the difference of size of the particles, and still more the different character of the minerals that made up those particles, to obtain entirely different results, both as to the fusibility of the mass and the solubility of the alumina that was present. The Author had made some reference in his paper to the electric smelting of zinc. A number of papers had been published on that subject in recent years, particularly by Canadians, and to some extent by Scandinavians, and many of the members would remember the particulars given by Dr. Stansfield, of Montreal, of experiments he made for the reduction of zinc in the electric furnace. It had been pointed out that one difficulty met with was the production of a large quantity of blue zinc, which it was very difficult to use, and for which there was only a limited application, in spite of the use of zinc dust in the gold industry at the present time. A more recent paper by Dr. Stansfield, not yet to hand, had been summarized in advance in the "*Journal of the South African Society of Mining and Metallurgy*." In that paper Professor Stansfield pointed out that there was at present little prospect of the electric

smelting of zinc becoming of general application; that it would only be possible in a few places where current was very cheap; and even there the difficulty connected with zinc fumes would be constantly present. Vacuum processes did not seem to give any solution to that difficulty, because even a very small leak of air entirely prevented any advantage which was otherwise obtained, and it was impossible in practice to prevent the presence of a small leak. Reference had been made to the hydrometallurgical process, and particularly to the deposition of zinc by electrolysis, either from zinc chloride, using less power and giving chlorine, as described by Mr. Mond, or from zinc sulphate. The questions that had ultimately to be decided, in connection with such processes for complex ores, was at what price the zinc could be got into solution; and, having got the zinc into solution, at what price could it be deposited from solution. There was not much difficulty in getting a comparatively pure zinc sulphate, in many cases, from complex ores. In dealing with zinc sulphate—assuming one knew how to get a compact and pure zinc, which was the first essential, and which was now known by many people—the ultimate question that arose was the cost of the current. Was the current obtainable in sufficient quantity, and was it sufficiently cheap? In many localities the answer would be in the negative, but in some localities it would be in the affirmative. In the localities that possessed complex ores and cheap electric current, it seemed to him there was a great future for ores containing both lead and zinc, from which it was possible to extract the zinc by solution, and deposit it in the form of a very pure zinc by means of cheap electric current. The insoluble residues containing the lead would be separately treated for the recovery of the lead and silver.

Dr. W. ROSENHAIN, F.R.S., Member of Council, said that the production of metals from their ores was not the aspect of metallurgy to which he had devoted attention, but there were a few points in the paper that had struck him as being of somewhat special importance and worth emphasizing. Professor Turner had already referred to the question of refractories. He only desired to add to what Professor Turner had said, that the question of refractories was proving to be a matter of vital importance in quite a number of industries. It was at least a coincidence that several industries which had flourished, particularly in Germany of recent years, were industries which required that particular attention should be paid to the character of refractories. The one with which he was personally largely concerned was the optical glass industry, and the glass industry generally, which very greatly depended upon the choice of the proper refractories, and apparently the zinc industry was very much in the same position. It was worth emphasizing that there more than anywhere else there was an urgent need for a systematic, extensive, and he would add, expensive research. The Author had referred among other things to the alloys

of zinc and aluminium. That had been a pet speciality of his for many years, and he desired to ask the Author to add a reference in his paper to the Tenth Report to the Alloys Research Committee, in which the whole question of the mechanical properties particularly of those alloys was very fully worked out. The general statements made by the Author were, he thought, in agreement with the results there given. One point which was perhaps worthy of special mention was the Author's remark that zinc-aluminium alloys containing more than 40 per cent. of zinc were valueless. They were from one point of view, but they possessed certain tempting properties. For instance, some of them (quite high in zinc) had been used for die-casting purposes, he was sorry to say, with disastrous results. He had seen die-castings made of some of these alloys which after a few years had swollen and practically disintegrated. That unfortunately had thrown, for a time at any rate, doubt upon the suitability and permanent value of the aluminium-zinc alloys generally: but he was able to say quite definitely, as the result of actual trial and careful watching of a large number of aluminium-zinc alloy castings, that the idea that they disintegrated spontaneously was incorrect so far as alloys with less than 30 per cent. of zinc were concerned. He thought that result was probably correct for anything between 30 and 60 per cent. of zinc. There was one point in connection with alloys which he wished to impress upon any representatives of the zinc industry present, namely, the absolute importance of pure zinc for the making of alloys. That not only applied to aluminium-zinc alloys, in which he had shown definitely that the presence of lead even in small quantities seriously reduced the value of the resulting alloy, but he believed it applied to copper-zinc alloys, and to the whole class of industrially important alloys of other metals. A great many of those other alloys when made with pure zinc and carefully handled produced results which were astonishingly good compared with what was obtained in the ordinary way industrially. There again there was an opportunity for improvement in a very important direction. As an Australian, he had been very much interested in some of the remarks made about the conditions in Australia concerning the zinc industry, and he desired in the first place to utter a mild protest with regard to what had been said on the subject of the Australian climate. Personally he thought the Australian climate was infinitely preferable to the climate of this country, and he would just as soon drive a furnace there as in England, in fact sooner. From what he had seen, all the men engaged in the zinc smelting industry in Australia were very healthy, and the difference in climate was not so great as most people imagined. Mr. Mond had raised a point which recalled an Australian experience of his own, namely, that the establishment of works at the two ends of a line of steamers had actually been carried out by the Broken Hill Proprietary Company. That company had their zinc smelters on the gulf in South Australia and their coal mines and iron works at Newcastle on the east coast. They carried their coal in the one direction from Newcastle

to Port Pirie, and they carried back their iron ore, which was also found there, to Newcastle, and secured that balance of freight in opposite directions which Mr. Mond referred to, and which was undoubtedly a point of vital importance where heavy and comparatively cheap materials had to be transported long distances. He desired, in conclusion, to express his appreciation of the paper, and to say that it was particularly valuable and interesting to one who, like himself, was not intimately acquainted with the details of the zinc industry.

Mr. H. KAYE (London) said that he desired to make a few remarks with reference to the German control of Australian concentrates, and the information he proposed to give had not, he believed, ever been made public before. The Metallgesellschaft, acting on behalf of the German Group, purchased for a number of years the whole supply of Australian zinc concentrates, and the price was regulated by the average of the mean daily quotations made on the London Metal Exchange. The Metallgesellschaft, through its Australian connection, The Australian Metal Company, and Hirsch & Company, through their indefatigable Australian representative, Mr. F. H. Snow, arranged the contract with the Broken Hill Groups. The contract was made so that if the price of spelter rose above £22 or £23 a ton, any excess above that price was divided equally between the buyer and the seller. That contract having been signed, the European Spelter Convention was formed about the middle of January, 1909. Spelter at that time was £21 10s. a ton, and he thought it was common knowledge that it was forced up to over £27 a ton. The higher price brought a remarkable increase in production so that the price, after touching over £27 a ton in 1911 and 1912 fell during the first half of 1913 to £22 a ton, and during July and August of the same year to about £20 10s. a ton. That was the correct history of the successful negotiations and contracts made by the German Group for the Australian concentrates. It was a mere question of £ *s. d.* or who would pay the highest price. As the Germans paid it, they obtained the Australian zinc concentrates.

Mr. A. R. LAMBERT (London) said that particulars were given on page 126 of the paper of the output of spelter in Japan, reference being made to the fact that the present smelting works were situated at Ohmuta and Osaka, and the statement being made that the former produced about twice as much spelter as the latter. That was wrong. As a matter of fact the Osaka works produced about twice as much as the Ohmuta. In 1914 the output of the Ohmuta works was 2900 tons, and that of the Osaka 5000 tons. In 1915 the output of the Ohmuta works was only 5200 tons, and not about 14,000 tons as stated in the paper, while the output of the Osaka works was 11,000 tons. The estimated total output of Japan for 1916 was 40,000 tons, of which quantity the Ohmuta works would produce about 9500 tons, the

Osaka works about 15,500 tons, and several new works whose combined production would supply the balance of about 15,000 tons.

Mr. H. M. RIDGE (London) congratulated the Author on his paper and regretted that there were a few points on which he must disagree with him. On page 123 the Author referred to the roasting of zinc ore for sulphuric acid, and to the fact that steps had first been taken in Silesia to prevent the deleterious effects that were caused by the emission of sulphur fumes. He believed that statement was incorrect. He possessed records showing that as long ago as 1868 or 1869, many years before the Silesians started making sulphuric acid from zinc blende, it was produced in connection with one of the works in Western Prussia. With regard to the question of American fireclays, comparative tests had been made in this country and in America of some European fireclays used largely for zinc retorts. They were looked upon in Germany as being the best clays that had been found for the purpose. He had sent samples over to America, and the results obtained agreed very well with the tests of what had been done over here, and they did not show that the American fireclays were inferior. It seemed to him that the inferiority claimed by various authors for American fireclay was due either to the treatment or to the handling they received. In other words, if what he said was correct the bottom was knocked out of what had been suggested as the reason for the inferior practice prevailing in America in regard to the reduction of zinc ores and the manufacture of spelter. On page 130 reference was made to one or two continental brands of spelter. He wished to point out that a large number of brands of spelter was made over there. Many of the works made two or three different brands varying in quality, mainly according to the lead contents, but in some cases dependent upon whether the metal is higher or lower in iron. They were sold at various prices, the better qualities naturally fetching higher prices, but it was misleading to mention a few names without giving a complete list. He thought not the slightest importance must be attached to the statement that the production of zinc ores in Silesia had slightly declined in 1913. Economic reasons existed for the Germans not using their mines and mining plant to the maximum capacity, especially in Silesia. The policy was being very strictly followed in Germany of conserving national resources. Several of the works there, particularly those of Hohenlohe and Giesche, had milling and concentrating plants which were being worked to somewhere between 30 per cent. and 40 per cent. of their possible capacity. Their mines were very much further developed and in a suitable condition for producing a much larger quantity of ore than they were actually mining, the reason being that they were carrying out the policy that, when they could buy ore on reasonable terms and make an excellent profit on the smelting, they preferred to buy the ore and leave their own ore lying in the mines for the future. Von Giesches

Erben possessed ore reserves which, at their rate of mining in 1914, were estimated to last for something like 120 to 125 years. In other words, no importance should be attached to the statement made in the paper to which he had referred. He believed the present development of the German spelter industry was in a very interesting condition. Information had been received in this country showing that Silesia was at the present time supplying the Western German smelters with zinc ore, in spite of the enormous distance and the high freights. Of course the ore could be carried the bulk of the distance by canal, but in spite of that it was normally not a commercial proposition. On page 139 the Author referred to the 300,000 tons of tailings that existed at Broken Hill. If the Author would not mind adding another "0" to the figure it would be more nearly correct,—i.e. 3,000,000 tons, although then it would be below the actual figure. The grade of 17 per cent. quoted for the zinc assay in 1904 was a good deal below the actual content of the dumps. There was a considerable tonnage, when he went there in 1899, carrying 27 per cent., in fact some of them which he treated himself in about 1900 went as high as 32 per cent. and 33 per cent. of zinc. That was of course picked material, and there was a large portion with 22 to 25 per cent., so that the average was probably between 20 and 24 per cent. On page 145 reference was made to the Siemens regenerative furnaces. Those were on the continent before the outbreak of the war only in use by one of the German groups and by their friends and connections in Belgium, but the furnaces that were for several years being built in Germany were no longer of the regenerative type; they were being dismantled to make way for the counter-current or recuperative furnaces. That development was going on exceedingly quickly in Silesia in the last two years before the war in consequence of the rapid increase in the price of coal, which made it imperative for the smelters to economize in fuel. By replacing the regenerative furnaces by counter-current recuperative furnaces, they reduced their fuel consumption appreciably, quite apart from getting better results. On page 146 the Author quoted a size of zinc retort which gave "a maximum charge thickness of about 8 inches." Eight inches could be obtained if a circular pot was used, but on the larger and more modern Rhenish retorts, the use of which was extending rapidly, it was quite impossible to work to anything like that size. With 6 inches of thickness of charge it became almost impossible to reduce the zinc oxide. It was necessary to go below that figure otherwise the heat units could not be got through the wall of the pot and right into the centre of the charge. He desired to confirm what Mr. Picard had said regarding the treatment of flotation concentrates. In one paragraph the Author referred to the loss of zinc in roasting. That had not been his experience at all, in fact he found that, with the product from the flotation process, it was decidedly easier to roast the ore and much more convenient to handle it afterwards than when treating material which was not crushed so fine.

Provided one did not allow the ore to lump and ball there was absolutely no trouble at all. Reference was made on page 147 to the new mechanical appliances which had been introduced for charging and cleaning the retorts. He agreed with what the Author said with reference to cleaning the retorts, that the machinery adopted had not been satisfactory up to the present time. On the other hand at least three of the Continental works had been working satisfactorily with mechanical charging machines for two or three years before the war. The results were good, and the costs were reduced, although not very largely, because the machinery was subject to wear and tear. The labour of skilled furnace-men was appreciably reduced. He thought it a pity that the product of the British smelters should be run down unnecessarily, as it was on page 161, where analyses were quoted showing 2.55 of lead in a virgin spelter. That might have been the case, but personally he had tried to put 2 or 3 per cent. of lead into the spelter, when he could sell lead as zinc, but he had been quite unable to do so. In his experience, if 2 per cent. of lead were present in the spelter one was bound to get lead settling out at the bottom of the ingot. He regretted the repetition of an analysis which, if correct, was decidedly unfavourable, when the bulk of the English production was much better than that. With regard to the question of the future of the spelter industry, the question would crop up as to the increased smelting capacity in America. America was not favourably situated to compete with our market. Even if the American smelters were willing and able to rely on domestic ore they could not commercially in normal times ship spelter to the United Kingdom. It only became possible when the spelter market was abnormally high here, and then they were able quite satisfactorily to do so because they regulated the market and prevented it rising to a prohibitive price. There was another side issue which he thought, while the question of spelter was under discussion, should be touched upon, namely, the manufacture and use of high-grade metal. He was very pleased to be able to state that before the war various works were producing in England a noticeable amount of high-grade metal, but unfortunately that had been stopped during the war. He was not referring to Messrs. Brunner Mond's works, which of course had gone on with their production, but of the almost pure metal obtained by distillation under certain conditions and used for the production of high-grade brass. Unfortunately the owners of those works were told that it was more desirable to produce common or garden spelter and send that abroad for refining instead of continuing an established British industry, which, strange to say, had never gone abroad. It was disastrous that this industry had been stopped here for the time being. That he thought was a great pity when one of the main questions that had to be faced in connection with the war was the supply of high-grade metal. For making cartridge cases it was essential to have a spelter which was practically free from lead, otherwise trouble would ensue. He could

not understand how it was that the question had not been rationally tackled. France since the outbreak of war had acted in quite a different manner. In 1914 France produced not an ounce of high-grade zinc, at the present time she was producing a very large tonnage. She had tackled the question successfully and satisfactorily in a way which he hoped would continue after the war, but this country had not dealt with the matter, although it was one of the articles on which it was absolutely dependent for war purposes. Brass users having once experienced the advantages of high-grade zinc for making brass were bound after the war, according to past experience, to continue its use. The economy was so great and the advantages were so manifold that brass makers would never go back to ordinary spelter if they could help it. In conclusion, he desired to again congratulate the Author on the most interesting paper he had produced.

Mr. SMITH, in reply, thanked the members for the very cordial reception that they had given to the paper, and for the interesting discussion it had evoked. It would only be possible for him in the short time at his disposal to reply very briefly to a few of the points that had been raised. Mr. Picard had drawn attention to the remarks made by Professor Bacon. Perhaps he (the Author) ought to have pointed out that Professor Bacon's remarks probably referred almost exclusively to American ores, and as he pointed out in the paper American practice was certainly behind European and Australian practice with regard to complex zinc ore concentration. He was indebted to Mr. Picard for his remarks in regard to the flotation process, especially as he was an authority on that subject. He regretted he had made the ambiguous statement which led Mr. Picard to think that he (the Author) suggested that the flotation process produced a lot of slime. That was certainly not his intention, and he thanked him for drawing attention to it. He also desired to thank Mr. Picard for the recent details he had given of the briquette process. Attention had been drawn by Professor Turner and others to the question of refractory clays for retorts. With Dr. Rosenhain he thought that a great deal more attention would undoubtedly be given in the future to the question of clays than had been devoted to it in the past. As Dr. Rosenhain had stated, one or two industries were already giving considerable attention to the subject. Reference might be made to a valuable paper, dealing with the problem of the most suitable type of refractory material for gas retorts, recently communicated to a meeting of Gas Engineers in Manchester, by Mr. John West. The paper contained much that would be helpful to the spelter industry.

The analyses of eight different clays suitable for spelter retort manufacture, and details of the requirements for a good retort were dealt with by Mr. Moulden in his paper before the Royal Society of Arts to which reference had been made.

In the selection of clays for retorts it was not altogether a question

of chemical composition; the physical condition of the clay was also of considerable importance.

Attention had also been drawn to the question of wet processes. It was very difficult in a paper which had to deal with so much to give fuller details of the wet processes now in use. He had not given more details because the question had been fully discussed by Mr. Ingalls in a very suggestive and able paper to which attention was drawn at the bottom of page 161.

He was obliged to Dr. Rosenhain for drawing attention to the full report on the aluminium-zinc alloys contained in the Tenth Report of the Alloys Research Committee. He endorsed what Dr. Rosenhain had said in regard to the use of pure zinc for alloys, and was of opinion that a good deal remained to be done in the way of research work in connection with the non-ferrous metallurgical industry and in the production of pure metals. Research work had shown that the presence of very small quantities of impurities had a very marked effect when the metals were used for alloying purposes, and metallurgists in the future would have to aim at giving the maker of alloys the purest possible metals that could be produced.

Although commercial spelter containing from 2 to 3 per cent. of lead was to be found on the market it was more usual to submit such metal to purification by liquation to remove the bulk of the lead before passing it into market.

He desired to thank Mr. Kaye for his remarks relating to the sale of Broken Hill concentrates, because such details as he had given were very seldom published. Mr. Lambert had given the figures relating to the Japanese industry. The Author confessed that he was more or less ignorant with regard to the Japanese industry, and if there were any errors in the figures contained in the paper they were due to the annual technical publication from which he had extracted them. Mr. Ridge had referred to a remark made on page 124 with regard to the utilization of the roast gases for sulphuric acid making, and suggested that he (the Author) had attributed the origin of the idea to Silesia. He thought, however, that if Mr. Ridge would read the paragraph carefully he would find that that was not the case. He (the Author) carefully said it had been taken up by the manufacturers in Silesia in common with other spelter manufacturers. With regard to the analyses of the brands of spelter, he had quoted those given by Mr. Primrose because they had already been brought before the Institute, and were so far as he knew the most recent analyses of European spelter, though he quite agreed with Mr. Ridge that the percentage of lead was much above the normal for ordinary English brands. In this connection he might quote the following more recent analysis by F. C. Moulden* of "virgin spelter" produced by the distillation of Broken Hill ore which might be taken

* *Journal of the Royal Society of Arts*, 1916, vol. lxiv, p. 512.

as typical of the composition of a good English spelter as produced at the present day.

	Per cent.
Zinc (by difference)	98.642
Lead	1.205
Iron	0.060
Cadmium	0.089
Copper	0.004
	<hr/> 100.000 <hr/>

The remarks of Mr. Ridge, relative to the gaseous firing of spelter furnaces by the recuperative principle, were of especial interest and value as bearing on the most recent practice in this connection.

Referring to the maximum thickness of the retort charge, given in the paper as about 8 inches, it should have been stated that this had reference to the older type of retort formerly in use in this country; the correction of Mr. Ridge was therefore opportune.

He would express his indebtedness to Mr. Mond for his very interesting contribution on the early experimental work in connection with the wet method of extraction and electrolysis of zinc which led eventually to the successful process now worked by Messrs. Brunner, Mond & Co. Such records of success, after years of steady experimenting and apparent failure, should act as an incentive to those engaged on experimental work on new processes.

COMMUNICATIONS.

Dr. CECIL H. DESCH (Glasgow) wrote that the spelter works at Irvine, which had been mentioned as using the process of fume filtration, were provided with modern machinery for making the retorts. A small but appreciable quantity of zinc concentrates was still produced at the very ancient lead workings of Wanlockhead in the Leadhills district of Scotland. If, as was to be hoped, the process of extracting zinc from blende should undergo further development and extension in this country, it was highly desirable that provision should be made in every case for the utilization of the sulphur dioxide for the preparation of sulphuric acid. It was well known that a large quantity of the German sulphuric acid was prepared from blende, and the roasting of blende without recovery of the sulphur was to be condemned as both wasteful and objectionable from the point of health and preservation of vegetation. According to the report of the Inspector of Alkali Works, arrangements had actually been made for the erection of works for roasting blende in which no such provision had been made. It was very desirable that such a procedure should be prohibited by legislation. This country had suffered badly in the past by the existence of wasteful and harmful metallurgical processes in certain areas,

and it should be impossible for similar nuisances to be established afresh. The works to be established for the production of spelter from the ores of the Empire should rather set an example of efficiency and healthfulness, instead of perpetuating the objectionable conditions of a less enlightened and public-spirited age.

Mr. W. DEWAR (London) wrote with regard to roasting plant that continental works, for the greater part, used hand furnaces—the older ones Hasenclever, the modern, De Place, which was an elaboration of the old Maletra shelf burner, and the best hand type.

To some extent the mechanical De Spirlet was employed and was well suited for continental conditions; the roast was equal to the hand furnaces; fuel consumption, zinc losses and dust were low, the motive power required moderate, and sulphur dioxide gases rich.

The Hegler furnace had very high fuel consumption and motive power, high dust and zinc losses and low sulphur dioxide, but it had the advantage that it could be manned by less skilled workmen. In America, where they had cheap fuel and expensive labour, they economized in the latter and paid less attention to the former.

In the Merton furnace various spots are not reached by the rabbles and dead corners occurred in which the ore was not touched; to remedy this the material had to be pushed back into circuit periodically.

The product from the Brown straight line type did not distil well as it was too open, the denser the roasted material the better the recovery of zinc.

The amount of lead lost in treating leady ores depended on the conducting of operations. Low temperature meant little lead, but zinc extraction would be correspondingly low; if the temperature were high to ensure the best extraction of the zinc a comparatively high percentage of the lead would go over with the zinc. The average loss of lead in distillation might be put down at between 15 and 20 per cent., that of silver being insignificant.

With a constant of zinc in the residues, the higher the percentage of metal in the ore the higher the percentage recovery, but physical differences gave rise to difficulties in reduction. Heavy but porous material could be reduced in a shorter time than a sintered product and as ferruginous blends tended in this direction they were apt to afford poor recoveries, and given the same plant, consumption of labour, coal, clay and recovery would vary with the character of the ore, so that higher percentage recovery alone and on different ores did not necessarily imply better economic or metallurgical work.

Professor Gowland had summed up the drawbacks to electric smelting. The technique of the method, as far as the reduction of zinc was concerned, had been fairly well worked out, but the criterion of a new metallurgical process was actual production of metal under actual commercial conditions at a greater profit than was possible under older and proved methods.

The present premium on pure zinc had encouraged the production of electrolytic metal, but to fall back on pre-war premiums would put a different complexion on its production. The Hoepfner process, however, afforded a useful anode reaction, advantage of which could be profitably taken.

There was little doubt that if a chemical substitute, such as zinc sulphate, could be obtained from ores, this branch of chemical metallurgy would increase enormously, as it would utilize a by-product in the alkali trade, viz. calcium chloride liquor, running to waste to the extent of hundreds of thousands of tons of actual calcium chloride per annum in this country.

There were classes of ores, e.g. those from the Tasmanian district of Mount Read, where the metals were held together in such an intimate state of fine division as to render concentration almost impossible. Chemical treatment was the only feasible and economic method of dealing with such ores; the ore roasted and the zinc extracted as soluble sulphate, leaving a residue containing the lead and precious metals which would be smelted for the recovery of these products. The purified solution of zinc sulphate passed over to the alkali works for conversion into chloride by means of the waste calcium chloride liquor, which on electrolysis would yield high-grade zinc and chlorine, the latter to be utilized for the manufacture of bleaching powder, chlorates, &c.

As to the future of the zinc industry it was difficult to prophesy, but this much seemed certain—that spelter reduction plants would be in excess of the world's average requirements, and that the contemplated extension of the industry would take time and necessitate careful and proper handling.

Mr. SMITH, in reply to the communications, wrote that regarding the remarks of Dr. Desch as to the utilization of the sulphur dioxide from blende roasting for the production of sulphuric acid, there was but little doubt that in this respect the zinc smelters in this country were behind the Continental and American smelters.

There were, however, indications that this matter would receive in the near future the attention that its great importance deserved.

Apart from the desirability of preventing the contamination of the atmosphere with fumes that caused damage or nuisance, the trend of modern metallurgical practice was to extract all the constituents of an ore whenever this could be done with advantage, and the question as to whether a constituent could or could not be utilized was largely governed by economic considerations.

As pointed out recently by Mr. Moulden, "it is now the practice in most European and many American works to carry on the blende roasting in conjunction with the manufacture of sulphuric acid, and this for two main reasons: (1) the restriction imposed by legislation in most thickly populated countries upon the discharge of sulphurous gases to

the atmosphere, and (2) the value of sulphuric acid in such localities due to the fact that they are usually also of industrial importance and consumers of the acid, and it therefore pays to utilize the sulphur.

"It is not uncommon in Europe to find the roasting and manufacture of sulphuric acid carried on in one district where the call for the acid is considerable, and the roasted ore distilled in another where conditions as to fuel, clay, and labour are the more favourable.

"Economic considerations govern, of course, each individual case, and this system has reached its most pronounced development in Belgium and Germany, largely owing to the abundant and cheap facilities for transport afforded by the various canal systems."

The rapid annual increase in the production of sulphuric acid in the zinc smelting district of Upper Silesia in recent years was shown by the following statement: *

"In 1900 the production of sulphuric acid per ton of raw zinc amounted only to 0.08 metric ton; in 1905 it had increased ten-fold to 0.85 metric ton, and in 1913 it still further increased to 1.34 metric ton."

He (the author) was indebted to Mr. Dewar for the interesting details relating to the various furnaces now in use for the roasting of blende.

The quantity of lead retained by zinc depended to a large extent on the temperature at which the metal was maintained during refining.

Thus it had been shown by Primrose that at 650° C. zinc would retain 5.5 per cent. of lead quite readily, but at its melting point (420° C.) it would only alloy with 1.5 per cent., so that even at the lowest possible temperature required to keep the metal molten there was always an objectionable quantity of lead retained.

With regard to wet methods of extraction, the economic success of these was largely dependent on the nature of the ore to be treated and local conditions, and also on the prevailing price of zinc.

The success of the electrolytic method adopted by the Anaconda Copper Company was, according to Ingalls, due to special circumstances. The zinc ore was mined in conjunction with copper ore and lent itself to very successful treatment by the flotation process, which gave a high-grade zinc concentrate. The nature of this concentrate was such that by roasting and subsequent leaching with dilute sulphuric acid a very high extraction of zinc sulphate was obtained.

The Anaconda process was based upon the electrolysis of this zinc sulphate in solution in dilute sulphuric acid; the plant was the largest so far erected for the wet extraction of zinc from its ores.

* *Board of Trade Journal*, Feb. 12, 1914.

NOTE.*

CADMIUM IN SPELTER.

BY WALTER RENTON INGALLS (U.S.A.).

FOR some purposes cadmium in spelter, even a small percentage of it, is deleterious. In spelter that is to be used for slush castings there is no doubt about it. In spelter for brass-making there is not the same certainty. For brass that is to be cast and machined, the adverse effect of cadmium is probably overestimated, and it may not be adverse at all. For cartridge brass it is by some regarded as objectionable, but not even with respect to that is there certainty.

As to what is the maximum percentage of cadmium permissible in spelter destined for the manufacture of cartridge brass, the best American authorities on brass-making say they do not know. Cartridge brass has been made successfully with spelter containing as much as 0.3 per cent. cadmium. Cartridge brass is ordinarily cast at a temperature considerably above the boiling point of zinc, which is far above the boiling point of cadmium, and it is generally impossible to find any cadmium in the brass, by the most careful analytical work, not even when the constituent spelter contains 0.3 to 0.4 per cent. cadmium. There is no doubt that large amounts of cadmium, say 1 or 2 per cent., make brass brittle, but it is hard to keep so much cadmium in brass anyhow. There is no reliable information at present respecting the effect of small amounts of cadmium in brass, and the evidence on this point is extremely conflicting.

So far as the author knows, it has been definitely established that cadmium is injurious only in spelter to be used for sheet-rolling, for galvanizing telephone and telegraph wires and for making ornamental (slush) castings. The Zinc Committee of the American Society for Testing Materials commits itself no further than this.

In many cases where cadmium is objectionable it is not unlikely that there is hair splitting about hundredths of a per cent. that is unnecessary. Military engineers and others who specify respecting brass should look carefully into this. The extraordinary differences in price that have lately prevailed, and still do to a less extent, between what in America are classified as high-grade, intermediate, brass-special and prime western (common) spelter do not look right.

* Taken as read at Annual Autumn Meeting, London, September 20, 1916.

The sampling of spelter is more or less of a haphazard process and has a bearing on this subject. American brass-makers follow a time-honoured practice of sampling a carload (about 50,000 lb. of spelter in 820 to 960 slabs) by drawing 10 slabs at random and that practice has within a few weeks received the tentative endorsement of the American Society of Testing Materials. This was the outcome of controversies that have arisen over that matter. The following, from an editorial by the writer,* may be appropriately quoted here :

"An interesting and entirely friendly controversy respecting the proper sampling of spelter recently arose between a well-known seller and an important brass manufacturer. The seller agreed to furnish two carloads of brass special spelter guaranteed to contain not more than 0.6 per cent. lead. The cars having arrived at the buyer's works, he drew 10 slabs from each and finding the assays to exceed slightly the stipulated lead content, called for an adjustment. The seller sent out the agent of a prominent firm of public assayers to draw a new sample of 30 slabs per car. The buyers refused in advance to abide by the result of this.

"The issue was clear-cut. The seller claimed that he should be required only to deliver a carload of spelter whereof the average should conform to the guarantee, that in determining the average a large sample is more desirable than a small one and that the conditions of producing spelter do not permit the insurance of uniformity in slabs except in the case of high-grade spelter.

"The buyer, on the other hand, contended that the conditions of brass-making whereby the spelter is introduced into the melting pots in small lots necessitate uniformity, that its method of sampling during many years had been to draw only 10 slabs at random out of a carload and that no other system would be safe for it.

"On none of these points have there been any official rulings. The specifications of the American Society for Testing Materials require as to sampling only that at least 10 slabs shall be drawn. In the contract between buyer and seller in this case, and probably in most of such cases, there was no contractual understanding.

"In the present instance the assays were made with the following results, those marked B being made by the buyer and those marked S by the public assayer acting in behalf of the seller :

Party.	Car.	No. Pieces.	Lead, per Cent.	Iron, per Cent.
S	1	30	0.491	0.013
S	1	12	0.644	0.012
B	1	10	0.737	0.013
S	2	30	0.758	0.021
S	2	12	0.616	0.023
B	2	10	0.667	0.021

"The interesting thing about these assays was that in the case of Car 1 the 30-slab sample showed lower lead than the 10-slab, while in the case of Car 2 it showed higher. The discrepancy between the

* *Engineering and Mining Journal*, July 8, 1916.

10-slab and the 12-slab samples is also noteworthy. Manifestly there was irregularity in the composition of the slabs.

"As to the merits of the case there is a good deal to be said for each side. The brass-maker needs uniformity of the product he is buying. On the other hand, the smelter can hardly insure it by his present methods unless he be distilling high-grade ore that is already uniform. In distilling ore containing lead, the proportion thereof that goes over with the zinc is governed primarily by the temperature of the retort, which varies in different parts of the furnace. In drawing the spelter, the kettle into which it is received holds but a relatively small quantity and the respective pourings from the same drawing may easily vary in composition, especially when lines are drawn so narrowly as they are as to lead content.

"Apparently there are two things that need to be done : (1) Sellers in offering a guarantee should specify as to whether it pertains to average of a carload or to any 10 slabs selected at random. (2) If buyers must have uniformity, smelters must insure it by pouring and mixing their product in large pots or melting furnaces before casting the slabs to be marketed."

It need only be added that if the zinc smelter be obliged to guarantee practically every slab of his production, the consumer must pay for it; or if he must introduce the new process of remelting and mixing, that also must be paid for.

Now, what are the conditions of the zinc smelter with regard to making spelter low in cadmium? His conditions are easy only when his ore is free from cadmium, but the only ore of that class produced in large quantity anywhere in the world is that of the Franklin mine of the New Jersey Zinc Co. That ore is also free from lead and that company is the only one that can produce high-grade spelter by a single and simple process of smelting. The bulk of the world's zinc ore contains cadmium, and that metal being metallurgically similar to zinc distills with the zinc and contaminates the spelter, as also does lead.

In America brass-special spelter is made by reserving the first of the three daily drawings of spelter. This metal having been distilled before the furnace has attained its maximum temperature is relatively low in lead, but in it there is a concentration of cadmium, which being volatile at a lower temperature than zinc comes over chiefly in the first stage of the distillation. Theoretically it should be possible to control the temperature of the distillation so as to cut off both the cadmium-bearing spelter and the lead-bearing spelter, obtaining a high-grade spelter between, but practically that would be quite out of the question. It is, however, easily possible to get a high-grade spelter, low in cadmium, by the redistillation of common spelter with proper control of the temperature and separation of the first distillate.

A good deal of the high-grade and intermediate spelter that America has sold to Great Britain at fancy prices during the last eighteen months

has been redistilled common spelter. Great Britain ought to have bought common spelter and redistilled it herself.

In conclusion, it may be remarked that the electrolytic process of zinc extraction affords an easy means for the separation of cadmium. It should be borne distinctly in mind that the electrolytic process is going to be commercially applicable only under some limited specially favourable conditions and is not going to drive zinc smelting out of the world's arts. However, the electrolytic zinc production that is likely to endure should go a long way toward meeting the demand for high-grade spelter and especially spelter low in cadmium. And, furthermore, inasmuch as the electrolytic cathodes have to be remelted in large furnaces, the slabs cast therefrom should be more uniform in composition than those coming from the small tapping kettles of the retort furnace, the Bertha and Horsehead brands excepted.

COMMUNICATIONS.

Mr. R. T. ROLFE (Bedford) wrote that Mr. Ingalls' Note, which might have been entitled "Cadmium and Lead in Spelter," was of great interest for the light it threw on a matter usually much neglected—the effect of cadmium in brass. This was generally considered as negligible; indeed the proportion of cadmium appeared never to be returned in the analysis of brass, while there was invariably no indication of its having even been looked for. Thus of about one hundred complete analyses of different brasses published in the *Journal*, not one mentioned cadmium, although very minute proportions of other elements were often recorded.

Mr. Ingalls stated (p. 196) that "it is generally impossible to find any cadmium in the brass, by the most careful analytical work, not even when the constituent spelter contains 0.3 to 0.4 per cent of cadmium. There is no doubt that large amounts of cadmium, say 1 or 2 per cent., make brass brittle, but it is hard to keep so much cadmium in brass anyhow." In the light of this statement, it would be valuable if Mr. Ingalls would state what quantities of cadmium had been found in his experience to occur in brass. It appeared that spelter might frequently contain in the region of 0.4 or 0.5 per cent. of cadmium and Mr. Arnold Philip had stated* that the ordinary zinc of commerce might not uncommonly contain as much as 2 per cent. of this impurity, but it appeared to be very doubtful how much cadmium might be found in the brasses manufactured from such zinc. Further information on these two questions, both as to the proportions of cadmium liable to be met with in brasses, and the effects upon their mechanical properties, would be very interesting.

With regard to lead, the grading of spelters according to the amount of this impurity was most desirable. A hard and fast classification did not appear to obtain in this country, and what were described as good ordinary brands showed a very large variation in the proportion of lead contained. Furthermore, different consignments of spelter of the same brand would often vary in this manner to an undesirable degree.

The samples analyzed were average ones from different consignments, taken at the dates given, and were obtained by drilling right through several plates (e.g., 3 plates from a $\frac{1}{2}$ -ton lot of 31 plates and *pro rata* in the case of larger lots); the drillings being cut or otherwise separated into very small pieces, which were then thoroughly mixed together.

* *Journal of the Institute of Metals*, 1910, No. 1, vol. iii. p. 209.

The following results, among others, had been obtained by the writer from different brands of spelter examined during the years 1913-1916 :

Brand.	Date of Sampling.	Lead per Cent.	Iron per Cent.
Revil	Sept. 19th, 1912	0.46	0.07
Revil	Mar. 31st, 1913	1.21	0.19
Nouvelle Montagne.	April 17th, 1913	0.94	0.03
Ste. de Boom	May 14th, 1913	1.65	tr.
S.S.	June 10th, 1913	0.32	tr.
De Boom	June 6th, 1913	0.31	tr.
Ste. de Boom	Sept. 15th, 1913	2.03	tr.
Vieille Montagne	Oct. 15th, 1913	1.47	0.07
S.S.	Oct. 30th, 1913	3.43	tr.
Vieille Montagne	Oct. 26th, 1914	1.49	0.04
Crown	Jan. 13th, 1915	1.52	0.08
Vivian & Co.	Mar. 19th, 1915	0.83	0.12
Vivian & Co.	May 19th, 1915	1.32	0.08
Revil	Mar. 14th, 1916	1.73	0.19

One of the above brands contained, in addition, aluminium to the extent, usually, of about 0.30 per cent., with some copper, and was probably a re-melted spelter.

These splterers were bought, at widely differing prices, over a long period, during part of which spelter conditions were very abnormal and therefore no suggestion was made that any particular brand mentioned above was better or worse than another according to the lesser or greater lead content. In the case in question, the splterers were being employed almost exclusively in the manufacture of gun-metal of Admiralty composition (88 : 10 : 2) and since no objection was raised to the presence of 0.5 per cent. of lead as a maximum in this alloy, the quantity of lead occurring in the splter was of slight importance.

Under other conditions, however, if for example the splterers were to be used for the manufacture of high-grade brasses, it obviously became necessary to limit rigidly the proportion of lead by specification and to sample carefully each lot delivered. From the figures given, it was clearly unsafe without checking to depend upon the constancy of a particular brand, one or more previous consignments of which may have proved satisfactory as regards lead content and in practice.

The various considerations affecting the question of uniformity of composition and the means of arriving at this had already been fully and excellently discussed by Mr. Ingalls. Under present conditions there was always a possibility of very considerable variation in a 20-ton carload of splter.

The method of sampling appeared to be only a matter of mutual

arrangement. The case quoted by Mr. Ingalls was not already provided for by existing agreements, but having once arisen, the possibility of a similar dispute in future could be obviated. In the case in question, the fairest method would have been to have abided by the results of the sample from the greatest number of plates, particularly as the 30-plate and 12-plate samples agreed very well with each other on averaging the two cars, assumed of equal weight. Thus for example :—

	Seller's 30-plate Sample.		Seller's 12-plate Sample.		Buyer's 10-plate Sample.	
	Lead per Cent.	Iron per Cent.	Lead per Cent.	Iron per Cent.	Lead per Cent.	Iron per Cent.
First car . . .	0.491	0.013	0.644	0.012	0.737	0.013
Second car . . .	0.758	0.021	0.616	0.023	0.667	0.021
Average of 2 cars .	0.625	0.017	0.630	0.0175	0.702	0.017

Thus each of the seller's average samples *over the whole consignment* assayed a little over 0.60 per cent. of lead, which was apparently what the buyer originally claimed. The seller having agreed to furnish (as stated on the second page of Mr. Ingalls' Note) two carloads of spelter, guaranteed to contain not more than 0.6 per cent. lead, had failed to do so, on the showing of both samples taken for his account.

Mr. H. KAYE (London) wrote that while Mr. Ingalls' Note might give the impression that some American consumers still objected to the presence of cadmium in spelter, his information was to the effect that practically all of the brass trade in the United States to-day ignored this element up to 0.40 per cent. in the manufacture of cartridge brass, German silver and similar alloys, this view being based upon the result of practical experience.

Chemists and metallurgists of the highest repute, also, were unable to determine with certainty the presence of cadmium in the alloy made with spelter containing up to 0.40 per cent. of cadmium, and interest in the investigation as to the effects of small percentages of cadmium in cartridge brass had perceptibly decreased because of the growing conviction that the subject bore no important relation to the superior performance either in brass mill practice or proof firing tests.

It was quite safe to assume that in America since August, 1914, more cartridge brass has been produced from high-grade spelter containing up to 0.5 per cent. cadmium than from cadmium-free high-grade spelter.

To the brass manufacturer a minimum content of lead and iron in zinc for cartridge and similar mixtures was of more importance, and there was at least one high-grade spelter made in America by the single and simple process of distillation from ores of unusual purity, which contained less lead and iron than the brands mentioned by Mr. Ingalls. The average of fifty assay certificates covering fifty carloads of American high-grade spelter made from virgin ores handled during the past few weeks was :

	Per Cent.
Cadmium	0.22
Iron	0.011
Lead	0.00823

Season cracking, which was formerly attributed solely to cadmium, was now recognized to be the result of internal strains, due to improper heat treatment or the entire lack of heat treatment.

In Great Britain 99.9 per cent. spelter was produced by re-distillation, and the difference in volatilization enabled manufacturers to separate the two metals.

Norwegian producers of high-grade spelter (also by re-distillation) expressly ignored cadmium, the general conditions of sale being that 99.9 per cent. spelter was guaranteed to contain, in the aggregate, not more than 0.1 per cent. of lead and iron (generally the proportions were 0.07 per cent. lead and 0.005 per cent. iron, the lead and iron contents being analyzed and the zinc contents taken by difference).

Manufacturing experts have held the view for many years that the objection to cadmium up to 0.5 per cent. on the part of metallurgists was based on laboratory practice only and not on the use in bulk of cadmium-bearing spelter (up to 0.5 per cent.) and since the outbreak of the war, when the manufacture of cartridge brass became a major industry, many of the most respected non-ferrous chemists and metallurgists in the United Kingdom had quietly accepted the view that cadmium up to 0.5 per cent. was only injurious when spelter was used for sheet rolling, for galvanizing, and for making slush (ornamental) castings.

Military engineers had been the last to accept the opinion that cartridge brass made from cadmium-bearing spelter fulfilled every necessary test, their revised specification for high-grade spelter permitting a maximum of 0.15 per cent. cadmium.

In this connection a report of proof firing tests on four 3-in. artillery cases, made in the ordinary routine of brass mill practice, with high-grade spelter carrying between 0.30 per cent. and 0.40 per cent. cadmium (other impurities being 0.009 per cent. lead and 0.01 per cent. iron) was of interest. It showed that the weight of charge varied from 24.5 to 26 oz., the projectile weight being 18.5 lb. and the mean pressure varying from 14.4 to 15.2 tons per sq. in. In all 73 rounds were fired, rounds 1 to 24, inclusive, in one gun, and rounds 25 to 73, inclusive, in another. The report concluded, after giving details of each shot,

“these cases are considered to have passed an excellent test in all respects.” The cases were fired at the proving grounds of one of the most eminent ordnance firms in America, and were passed by British inspectors.

There were many more important matters awaiting investigation, and when times became normal, the co-operation of representative technicians, whose verdict would not be biased by commercial interest, should be sought to fully investigate the subject of Mr. Ingalls' Note.

NOTES FOR AUTHORS ON THE PREPARATION OF PAPERS FOR THE "JOURNAL OF THE INSTITUTE OF METALS."

The following notes, which have been drawn up by the Publication Committee, are intended for the guidance of prospective authors who may prepare papers for presentation before the Institute of Metals.

(A) FORM OF PAPER.—The MS. should be in such a form that in the proofs only printer's errors should necessitate type alterations.

Papers should, whenever possible, be *typed with double-line spacing*. In the case of *lengthy Papers a Summary* should be given. In addition, an *abstract, not exceeding 200 words*, and suitable for publication in the general press, should be provided.

(B) NOMENCLATURE OF ALLOYS.—Authors are invited to adopt the *Alloy Nomenclature*, as recommended in the "First Report of the Committee on the Nomenclature of Alloys" (*Journal of the Institute of Metals*, No. 1, 1914, Vol. XI.). The Recommendations are as follows:—

Brass.—The term "brass" is to be used as an abbreviation of the words "zinc-copper" as employed in the systematic nomenclature. Thus when the word "brass" alone is employed it shall denote an alloy of zinc and copper only, containing more copper than zinc, i.e. containing over 50 per cent. of copper. When an alloy intentionally containing a third metal, such, for example, as tin, is to be denoted, the name of the additional element shall be used as a prefix, precisely as in the systematic nomenclature. Thus an alloy containing tin 1 per cent., zinc 29 per cent., and copper 70 per cent. would be called "tin-brass." If additional metals are present their names may also be prefixed, or the general prefix "comp." or "complex" may be used if it is not essential to mention the other elements specifically.

Bronze.—The term "bronze" is to be used as an abbreviation of the words "tin-copper" as employed in the systematic nomenclature. Thus when the word "bronze" alone is employed it shall denote an alloy of tin and copper only, containing more copper than tin, i.e. containing more than 50 per cent. of copper. The presence of one or more intentionally added metals shall be denoted in the same manner as has been indicated above in the case of brass.

(C) ABBREVIATIONS.—Commonly accepted abbreviations should be used, as, for example, c.c., mm., lb., °C. With regard to the latter, temperatures should invariably be given in Centigrade, though Fahrenheit may be added if thought desirable.

(D) ILLUSTRATIONS AND TABLES.—Authors should indicate in the text where, as far as may be practicable, *Illustrations* and *Tables* should appear. If Authors do not indicate this the Editor will use his dis-

cretion in the matter and it will not be possible subsequently to alter the position of the Illustrations or Tables.

(E) PLATES.—As the Institute desires to publish photomicrographs in a satisfactory manner by reproducing this class of illustrations on *Plates*, Authors are requested to restrict the number of photomicrographs as much as possible on account of the considerable expense involved. In order to avoid the multiplicity of magnifications which results from reducing photomicrographs in reproduction, Authors should send photomicrographs trimmed to one of the sizes stated below :

4" × 3"	(representing 2 photomicrographs to a plate)				
2 $\frac{1}{4}$ " × 3"		4		"	"
2 $\frac{1}{4}$ " × 2"		6		"	"

Or a circle having a diameter the same as that of the lesser dimension of any of the above three sizes may be adopted. Photomicrographs submitted in accordance with the above sizes will be reproduced full size. *Authors should in every case adopt the smaller size consistent with adequate representation of their subject.* In taking photomicrographs for reproduction Authors are requested to adhere to magnifications expressible in multiples of 10 diameters. Although rigid uniformity cannot invariably be adhered to, the following magnifications are suggested for general use :—

10, 50, 100, 150, 300, 600 and 1,000.

Photomicrographs should invariably be printed on glossy paper.

Each photomicrograph should have below a title indicating the principal features represented.

Under each photomicrograph (or at the foot of the Plate if these are all similarly treated) there should be given the magnification (and N.A. of objective in the case of high magnification), also the method of developing the structure (etching, &c.), mechanical and/or heat treatment, and illumination (if the latter is in any respect exceptional).

(F) DIAGRAMS.—Diagrams should be made on *smooth paper*, or Bristol board. Papers with *rough surfaces* should be avoided.

Where there is *much detail* in the diagrams *large scale* drawings are best.

Diagrams in which there is little or no detail should be drawn the size that they are desired to occupy within the typed area of the page (4 in. × 6 $\frac{1}{2}$ in.). Reproductions can then be made the same size as the drawings.

(G) LETTERING OF DIAGRAMS.—The descriptive *lettering* on the diagrams should be *in pencil* to allow of the lettering being re-drawn in a suitable size and manner for reproduction and to bring about desirable uniformity.

A brief description should be given underneath each Illustration.

Authors whose Papers are accepted for publication receive 50 reprints of their Paper either with, or without, the Discussion and/or Communications, according to their preference.

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ROLL OF HONOUR.

MEMBERS KILLED IN ACTION.

- GRAZEBROOK, R. (Engineer Lieut. H.M.S. *Cressy*). (See p. 308, Vol. XIII., No. 1, 1915.)
- GUERNSEY, The Right Hon. Lord (Captain, Irish Guards). (See p. 261, Vol. XII., No. 2, 1914.)
- JOHNSON, W. MORTON (Captain, 16th Manchester Regiment). (See p. 210, Vol. XVI., No. 2, 1916.)
- MAIN, R. (Engineer Commander, H.M.S. *Invincible*). (See p. 333, Vol. XV., No. 1, 1916.)
- NARRACOTT, R. W. (Captain, Royal Engineers).
- TAYLOR, C. G. (Engineer Captain, H.M.S. *Tiger*). (See p. 309, Vol. XIII., No. 1, 1915.)

MEMBERS SERVING WITH THE BRITISH AND ALLIED FORCES.

- ASH, H. E. H. (Engineer Commander, R.N.).
- ASH, P. C. M. (Captain P.O. Rifles).
- AYERS, R. B. (Engineer Commander, R.N.).
- BENGOUGH, G. D. (Captain, Royal Garrison Artillery).
- BRADLEY, B. (Major, 9th Batt. P.A. Somerset Light Infantry).
- CARNT, A. J. (Engineer Commander, R.N.).
- CARRUTHERS, D. J. (Engineer Commander, R.N.).
- CARTLAND, J. (Second Lieutenant, 8th Royal Warwickshire Regiment).
- CHAMBERS, D. M. (Captain, 16th Durham Light Infantry).
- COE, H. I. (Lieutenant, 18th (Service) Batt. Welsh Regiment, B.E.F.).
- COLVER, E. DE WYKERSLEY SWIFT (Lieutenant, King's Own Yorkshire Light Infantry).
- COURTMAN, E. O. (Captain, Royal Engineers).
- CROSIER, E. THEO. (Middlesex Regiment).
- DIXON, R. B. (Engineer Commander, R.N.).
- EMDIN, A. R. (Engineer Captain, R.N.).

- EVANS, U. R. (Lieutenant, 5th East Surrey Regiment, attached 67th Div. Signal Co., R.E.).
- GARLAND, H. (Egyptian Army).
- GARRETT-SMITH, N. (Second Lieutenant, 8th Lancashire Fusiliers, Territorial Force).
- GIBSON, H. (Leeds Batt. W. Yorkshire Regiment).
- GOODWIN, G. G., C.B. (Engineer Rear-Admiral, R.N.).
- GROVES, C. R. (Chemist, Royal Engineers).
- HAM, J. W. (Engineer Captain, R.N.).
- HAMILTON, G. M. (Captain, Royal Field Artillery, T.F.).
- HEATH, W. S. (Officers' Cadet Battalion, Lichfield).
- HENDRY, P. W. (General).
- HEYCOCK, C. T. (Colonel, 1st Reserve Batt. Cambridgeshire Regiment).
- HUNTER, SUMMERS, Jnr. (Engineer Lieutenant, R.N.).
- HUMPHRIES, H. J. (City of London Red Cross Voluntary Aid Detachment).
- HURBURGH, L. H. (Corporal, Honourable Artillery Company).
- HUSSEY, A. V. (186th Company, London Electrical Engineers, R.E.).
- LIVERSIDGE, E. W. (Engineer Captain, H.M.S. *Shannon*, 2nd Cruiser Squadron).
- McLAURIN, J. (Engineer Commander, R.N.).
- McWILLIAM, A. (Captain, Chota Nagpur Light Horse, Volunteers).
- MARSHALL, F. W. (Engineer Commander, H.M.S. *Monarch*, 2nd Battle Squadron).
- MENZIES, J. (Colour-Sergeant, London Scottish).
- MERRETT, W. H. (Major, London Electrical Engineers, R.E.).
- MORCOM, R. K. (Captain, Royal Engineers).
- MORISON, R. B. (Engineer Commander, R.N., H.M.S. *Canada*).
- MORTIMER, J. E. (Engineer Commander, R.N.).
- MENEGHINI, D. (Second Lieutenant, Italian Army).
- NEVILL, R. W. (Lieutenant, Leicestershire Regiment).
- ONYON, W. (Engineer Captain, R.N.).
- ORAM, Sir H. J., K.C.B., F.R.S. (Engineer Vice-Admiral, R.N.).
- PLANT, A. E. (Captain, 1st Army Service Corps Repair Unit, British Expeditionary Force).
- RANDALL, C. R. J. (Engineer Lieutenant Commander, Squadron Commander, Royal Flying Corps, Naval Wing).
- READ, A. A. (Captain, Welsh Regiment, T.F.).
- RICHARDS, A. J. (Engineer Commander, R.N.).
- SHEPPARD, R. M. (Second Lieutenant, 6th Reserve Batt. S. Staffs Regiment).

- SILLINCE, W. P. (Engineer Lieutenant, R.N.).
SITWELL, N. S. H. (Captain, Royal Artillery).
STANLEY, W. N. (Sergeant, 5th Batt. Reserve E. Surrey Regiment).
TEED, H. R. (Engineer Captain, R.N.).
TUCKER, P. A. (15th Service Batt. Royal Warwickshire Regiment).
VIVIAN, The Hon. ODO (Major, Glamorgan Yeomanry).
WEIR, J. G. (Captain, Royal Field Artillery, T.F.).
WIGGIN, C. R. H. (Captain, Staffordshire Yeomanry).
WISNOM, W. M. (Engineer Commander, R.N.).
WOOD, W. H. (Engineer Commander, R.N.).
WRIGHT, R. (Lieutenant National Reserve, E. Lancs. Division).

OBITUARY.

WILLIAM GEMMELL was born in Glasgow, March 1885. His untimely death, which occurred at Silloth on 1st of September 1916, was due to burns resulting from an explosion which occurred whilst carrying out valuable work for his country.

He served his apprenticeship with Messrs. Tatlock & Thomson, public analysts, and later entered the employ of the Glasgow Corporation. In 1906 he joined the staff of the Metallurgical Department of the National Physical Laboratory. In 1912 he entered the service of Messrs. Sir W. G. Armstrong, Whitworth & Co. Ltd., Newcastle-on-Tyne, as chief chemist.

Mr. Gemmell during his too short career was universally esteemed and highly respected by his employers and staff. He devoted much of his time to metallurgical chemistry, and had several original works to his credit, amongst which the following are to be found in the *Journal of the Society of Chemical Industry* :—

- (a) The determination of phosphorus in phosphor-tin.
- (b) The analysis of copper-tin alloys.
- (c) A special apparatus for the electrolytic determination of lead in brass.

He was connected with O. Smalley in a patent which has proved very successful in connection with high-speed cutting steels. His record of published work is not vast, but what achievement he had made gave great promise of a most successful career.

He was elected a member of the Institute in 1914.

WILLIAM MORTON JOHNSON, Captain, Manchester Regiment, M.A., F.R.G.S., was the eldest son of the late William Henry Johnson, B.Sc., of Woodleigh, Altrincham, Chairman of Messrs. R. Johnson, Clapham & Morris, Ltd., metal merchants, Manchester. Captain Johnson was born on September 2, 1881, educated at Summer Fields, near Oxford, at Harrow and Trinity College, Cambridge, where he took the History Tripos. Always a lover of history and geography he had read widely in these subjects, and had travelled extensively.

After leaving the University he entered his father's firm and on the death of his father became the Chairman and a Managing Director. Captain Johnson took a great interest in the welfare of the employees ; some 450 attended the Memorial Service held in St. Margaret's Church Altrincham, to show their respect and esteem for him. Captain Johnson was a great lover of children—many little orphan children in Manchester will never forget the happy "joy" rides he took them in his motor when they came out to spend the day at Woodleigh.

On the outbreak of war Captain Johnson joined the army as a private in the Public Schools' Battalion, but was shortly after given a commission in the Manchester Regiment, and subsequently became a Company Commander. He was first through the village of Montauban on July 1, and chalked his regiment's name on three German guns. A brother officer wrote : " During the advance to, and the consolidation of, the village Captain Johnson acted throughout with the greatest bravery and coolness. It was mainly through his ability and foresight that the front of the village was put in such an excellent state of defence, and the men so disposed, that we were able to beat off the counter-attack when it came. He was buried where he fell with the men of his Company who died with him. The battalion has lost in him an excellent and able officer whom it will be difficult, if not impossible, to replace, and we officers have lost a personal friend whom we all admired and loved."

Captain Johnson was president of the Australian and New Zealand section of the Manchester Importers' and Exporters' Association, and, like his father, was also an original member of the Institute of Metals.

ADDITIONS TO THE LIBRARY

DURING 1916

	By whom Presented. <i>The College.</i>
Armstrong College : Calendar for 1916-1917.	
Canada : "The Production of Copper, Gold, Lead, Nickel, Silver, Zinc and other Metals in Canada during the Calendar Year 1914."	<i>The Director.</i>
Canada : "Preliminary Report on the Mineral Production of Canada during the Calendar Years 1914 and 1915." By J. McLeish.	"
Canada : "Description of the Laboratories of the Mines Branch."	"
Engineering Standards Committee : Report No. 72. "British Standardization Rules for Electrical Machinery (excluding motors for traction purposes)."	<i>The Committee.</i>
Engineering Standards Committee : Report No. 75. "British Standard Specifications for Wrought Steels for Automobiles."	"
Engineering Standards Committee : Report No. 76. "British Standard Nomenclature of Tars, Pitches, Bitumens and Asphalts, when used for road purposes, and British Standard Specifications for Tar and Pitch for road purposes."	"
Hong Kong University : Calendar for 1916-1917.	<i>Prof. C. A. M. Smith.</i>
Lewis, W. C. McC. : "A System of Physical Chemistry." Vols. I and II. Edited by Sir William Ramsay.	<i>Longmans, Green & Co.</i>
"Metal Statistics, 1916."	<i>The American Metal Market Co.</i>
Committee of the Privy Council for Scientific and Industrial Research : Report for the year 1915-1916.	<i>The Council.</i>
Wood, R. A. : "The Waterbury Book of Alloys."	<i>The Author</i>
"Quin's Metal Handbook and Statistics, 1916."	<i>Purchased.</i>

The following specimens have been presented to the Museum :

	By whom Presented.
Specially pure (99.95 per cent.) electrolytically-produced Zinc, of similar quality to Brunner Mond's, but produced by a different process by Chance & Hunt, Ltd.	Chance & Hunt, Ltd.
Molybdenum Ore.	A. E. Seaton, Esq.
2 pieces of badly-corroded condenser tubes.	The Editor, "The Engineer."
1 piece of corroded brass boiler tube.	Dr. Cecil H. Desch.

Several specimens of Tungsten Ore—Wolframite.

1 piece of Pure Muntz Metal:—60 per cent. Copper, 40 per cent Zinc.

1 piece of Muntz Metal containing 0·03 per cent. Arsenic.

By whom
Presented.
Mr. Moore.

Sir Gerard Muntz,
Bart.

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American Electro-Chemical Society.
American Institute of Metals.
American Institute of Mining Engineers.
Chemical Society.
Concrete Institute.
Faraday Society.
Franklin Institute.
Imperial Institute.
Institute of Marine Engineers.
Institution of Automobile Engineers.
Institution of Civil Engineers.
Institution of Electrical Engineers.
Institution of Engineers and Shipbuilders in Scotland.

Institution of Mechanical Engineers.
Institution of Mining and Metallurgy.
Institution of Naval Architects.
Iron and Steel Institute.
North-East Coast Institution of Engineers and Shipbuilders.
Ottawa Department of Mines.
Royal Society of Arts.
Society of Chemical Industry.
Staffordshire Iron and Steel Institute.
West of Scotland Iron and Steel Institute.
Washington, Department of Commerce and Labour.

JOURNALS.

The following periodicals are received regularly from their respective Editors:—

UNITED KINGDOM.

Chemical Trade Journal.
Civil Engineering.
Colliery Guardian.
Commercial Motor.
Engineer.
Engineering.
Hardware Trade Journal.
Hardwareman and Ironmongers' Chronicle.
Iron and Coal Trades Review.
Ironmongers' Weekly.
Machinery.
Marine Engineer.
Mechanical Engineer.
Metal Industry.

Mining Journal.
Mining Magazine.
Motor Traction.
Motor Trader.
Nature.
Page's Engineering Weekly.
Practical Engineer.
Railway Engineer.
Railway News.
Shipbuilder.
Shipbuilding and Shipping Record.
Steamship.
Tramway and Railway World (Motor Traffic Section).

COLONIAL AND FOREIGN.

American Machinist.
Automobile.
Automobile Engineer.
Brass World and Platers' Guide.
Engineering and Mining Journal.
Industrial Management.
Journal, Chemical, Metallurgical, and Mining Society of South Africa

Journal du Four Electrique et de l'Electrolyse.
Métaux et Alliages.
Revue de Metallurgie.
South Africa.
South African Engineering.
Steel and Metal Digest.

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Board of Studies, Royal Technical College, Glasgow.	Manchester University.
British Museum.	National Library of Wales.
Cambridge University.	National Physical Laboratory.
Cardiff University.	Patent Office.
City and Guilds Engineering College.	Royal School of Mines.
	Sheffield University.
	Trinity College, Dublin.

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SECTION II.

*ABSTRACTS OF PAPERS
RELATING TO THE NON-FERROUS METALS AND
THE INDUSTRIES CONNECTED THEREWITH.*

CONTENTS.

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THE PROPERTIES OF METALS AND ALLOYS.

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I.—PROPERTIES OF METALS.

Allotropy.—A general review of the newer theories of allotropy is given by J. W. Terwen.* The article is mainly based on the theory of Smits, and much evidence is collected in its favour. Cohen's recent papers, in which allotropy is assumed to occur in most of the common metals, are not taken into account.

The application of Smits' theory of dynamic allotropy to electro-motive equilibria is discussed mathematically by A. Smits and A. H. W. Aten.†—C. H. D.

Aluminium, Action of Nitric Acid on.—In view of the increasing use of aluminium vessels in the manufacture of nitric acid and of nitro-explosives, R. Seligman and P. Williams‡ have made extensive experiments to determine the degree of resistance of the metal under different conditions to the pure acid and to nitrating mixtures. Previous statements on the subject have been very conflicting, especially in regard to the action of mixed nitric and sulphuric acids.

All experiments were made with thin rolled strips, immersed in acid in stoppered bottles in a thermostat at 20° C. The strips were annealed and cleaned with caustic soda and nitric acid before use, but even with these precautions the action was often irregular at first. As the initial effect is of no importance, the action was always continued until the loss of weight became quite regular, and the strips were then transferred to fresh acid and the experiment proceeded with. In all cases when good aluminium sheet was used, the metal was dissolved quite uniformly, without any local pitting.

* *Zeitschrift für physikalische Chemie*, 1916, vol. xci. p. 443.

† *Proceedings of the Royal Academy of Sciences, Amsterdam*, 1916, vol. xix. p. 133.

‡ *Journal of the Society of Chemical Industry*, 1916, vol. xxxv. p. 665.

The loss of weight is expressed as milligrammes per square decimetre per 24 hours. This rate increases very rapidly with the temperature, the variation of the logarithm of the rate with the temperature between 20° and 90° C. being almost exactly linear. Above 90° there is a change in the curve, probably owing to the rapid evolution of gas. At 20° C. the maximum action is produced by an acid containing about 22 per cent. of HNO_3 , corresponding with a mixture of one part of the ordinary concentrated acid with three parts of water by volume. With concentrated acids, the rate of action increases in a linear manner with the percentage of added water. Fuming acid, prepared from the atmosphere, has very little action, and even this ceases after a short time, owing to the formation of a film of silicon, which is not loosened so long as the acid remains anhydrous. Chlorine and iodine, in such quantities as are likely to occur in commercial nitric acid, have very little effect on the rate of solution, but even traces of sulphuric acid may double the rate of attack of the 1.42 acid on aluminium. The lower oxides of nitrogen have a great accelerating effect.

As might be expected, hard-worked aluminium is more readily attacked than the annealed metal, and cast aluminium more readily than either. Some anomalies have, however, been observed. Thus exposure for some hours to a temperature of 125° C. partially anneals the metal, but longer heating at that temperature again increases the liability to attack. Freshly annealed metal (at 540°) is more resistant than metal which was annealed ten days before use. Within the ordinary range of composition of the commercial metal, variation of the impurities is comparatively without effect, and even 1 per cent. of copper has little influence on the resistance to concentrated acid, although it accelerates the action of dilute acid.

Mixtures of nitric and sulphuric acids in various proportions, whether the former be of 1.5 or 1.42 strength, act much more rapidly than the pure acid. This statement is opposed to the information given by several previous writers.

The conclusion is drawn that aluminium may be used with advantage for cold, strong nitric acid, but that its life when dilute acid is used will be much shorter. Storage tanks of aluminium should be well washed out after use, or sealed so that moisture cannot enter and dilute the acid. Where aluminium is used for domes and covers for mixed acid tanks, care should be taken to prevent splashing.—C. H. D.

Aluminium, Electrical Position of.—A note by Ch. M. van Deventer* remarks that aluminium is electro-positive to zinc in dilute sulphuric or nitric acid, but that amalgamated aluminium is electro-negative to zinc.—C. H. D.

* *Chemisch Weekblad*, 1916, vol. xiii. p. 475.

Base Metals, Catalytic Action of.—In the reduction of organic compounds by hydrogen in presence of catalysts, it is shown by C. Kelber * that platinum and palladium may be replaced by base metals without increasing the temperature or pressure, provided that the catalyst is suitably prepared. Thus nickel may be reduced from the carbonate, previously distributed over the surface of a suitable material, such as infusorial earth or the commercial hydrosilicates of aluminium or magnesium. Animal charcoal may also be used. Nickel reduced from the carbonate at 450° C. is inactive towards a mixture of hydrogen and oxygen at the ordinary temperature, but if distributed over 9 times its weight of an inorganic carrier, it is as active as colloidal palladium. The nickel is still more active towards organic compounds if reduced at a lower temperature, 310° C.

Cobalt acts in a similar manner to nickel, but less rapidly.—C. H. D.

Bismuth, Electrical Properties of.—A theoretical paper by T. Heurlinger † discusses mathematically the effects produced by direct and alternating currents in bismuth in a transverse magnetic field and also the "electrical after-working" under the same conditions. It is shown that the magnitude of the observed effects is of the same order as that which is indicated by theory.—C. H. D.

Bismuth, Purification of.—The detection of minute quantities of impurities in nominally pure bismuth is, according to F. Mylius and E. Groschuff, ‡ very difficult on account of the colloidal character of most of its insoluble salts, whilst the basic chloride and nitrate, which are crystalline, carry down several impurities. Fractional precipitation of the basic nitrate gives a very pure product, but the yield is very small. Crystallization of the normal nitrate from cold nitric acid, especially if repeated several times, gives the purest product. This nitrate is decomposed by heat and reduced by means of pure potassium cyanide. Remaining traces of metallic impurities are best removed by fractional crystallization of the fused metal under paraffin. The first crystals are collected by means of a perforated glass spoon. Detailed analyses of samples of bismuth from different sources are given, the impurities varying from 0.2 down to less than 0.01 per cent., the latter figure representing the purest bismuth of Kahlbaum. The only impurity present in this metal in recognizable quantity is copper.

The corrected melting point of bismuth, determined with full precautions, is 271° C. The specific electrical resistance is 1.20, higher values being given by impure metal.—C. H. D.

Calcium.—Metallic calcium being frequently used as an absorbent

* *Berichte der deutschen chemischen Gesellschaft*, 1916, vol. xlix. p. 55.

† *Physikalische Zeitschrift*, 1916, vol. xvii. p. 221.

‡ *Zeitschrift für anorganische Chemie*, 1916, vol. xcvi. p. 237.

for gases, A. Sieverts* has investigated its behaviour in this respect. The activity depends on the fineness of grain. Coarsely crystalline calcium, obtained by cooling the metal slowly from the molten state, absorbs nitrogen even below 300° C., whilst calcium quenched from 1000° is less active. Both are brittle, but by quenching from 840° C. a tough, ductile metal is obtained which is almost completely inactive. Mechanical disintegration does not increase the activity. No indication of allotropic change has been detected by means of cooling curves. The behaviour towards hydrogen is exactly similar. The nitride or hydride retains the external form and lustre of the original calcium crystals. Calcium nitride also absorbs hydrogen and other gases. The differences between different specimens of calcium are not to be attributed to impurities, the analyses being identical.—C. H. D.

Conductivity, Electron Theory of.—In a theoretical paper, A. March† obtains a formula by means of the quantum hypothesis which connects the number of free electrons with the free period of vibration of the metallic atoms. From this relations between the conductivity of an alloy and that of its component metals may be deduced, the relation being tested by its application to the alloys of gold and silver and of gold and copper.—C. H. D.

Conductivity at Low Temperatures.—Measurements of the thermal conductivity of metals at low temperatures by R. Schott‡ show that the values for copper vary widely with the size of the crystal grains, and that the ordinary measurements therefore fail to determine the concentration of the electrons, other factors intervening. W. Meissner§ refers to the influence of impurities on the ratio of the thermal and electrical conductivities, impurities affecting the former far less than the latter.—C. H. D.

Crystals, Plasticity of.—A long article by O. Lehmann, with over 200 references, reviews the theories which have been put forward to explain the plasticity of crystals. The author rejects all theories of regelation and of an amorphous phase, and regards all changes, such as hardening by work, which go beyond simple translation along gliding planes, as being due to polymorphic change brought about by deformation.

It is stated, on the authority of the firm of Julius Pintsch, that a filament of colloidal tungsten, forced through a die and then passed through a heating spiral and heated nearly to the melting point, issues as a single crystal, provided that the velocity with which it passes

* *Zeitschrift für Elektrochemie*, 1916, vol. xxii. p. 15.

† *Annalen der Physik*, 1916 (iv.), vol. xlix. p. 710.

‡ *Berichte der deutschen physikalischen Gesellschaft*, 1916, vol. xviii. p. 27.

§ *Ibid.*, p. 240.

|| *Annalen der Physik*, 1916 (iv.), vol. l. p. 555.

through the die coincides with the velocity of crystalline growth. This is also considered by the author as a case of polymorphic change, and not merely of recrystallization of flowed metal by heat. The author's view is that in all such cases the molecules are changed, and not merely the arrangement of the molecules in a space-lattice. Twinning under the influence of heat is also attributed to the formation of a new modification, in parallel orientation to the old crystals. It is stated that whilst cold-worked iron is more readily attacked by acids than the annealed metal (Osmond and Werth, Goerens), copper, aluminium and lead are less readily attacked after cold-working (Heyn). It is concluded that deformation of the space-lattice alone is without influence on the solubility and that where changes of solubility occur they must be attributed to polymorphism. This is supported by experiments with strongly bent crystals of ammonium nitrate. The supposed absorption of small crystals by large, and the growth of one crystal face at the expense of another, are attributed to variations of temperature, and it is denied that any such effects occur at constant temperature.

"Forced homotropy," or the re-arrangement of molecules either parallel or transversely to the direction of stress, is easily observed in soft crystals, and probably also occurs in metals. The phenomena of elastic creeping are attributed to the simultaneous presence of two or more polymorphic modifications, which gradually change into one another.

The names of Ewing and Rosenhain and of Beilby are only mentioned in passing, and the author has not understood the results contained in their papers. Beilby's theory of the production of an amorphous modification during deformation is quite wrongly interpreted. Further, references are given to the investigation of the space-lattice by means of X-rays, but the name of Bragg is not included.—C. H. D.

Films, Change of Resistance of.—Metallic films prepared by cathodic "sputtering" are known to change in resistance with time. According to Miss E. W. Hobbs,* films of platinum and palladium, deposited on polished strips of fused silica in air, show a gradual fall of resistance *in vacuo*, a steady state not being reached for some days. It is suggested that the amorphous deposit may become crystalline, but no evidence is adduced. The same effect occurs when hydrogen is used instead of air. The resistance rises again when gas is admitted, this effect being attributed to absorption of gas by the metal.—C. H. D.

Gold and Lead, Space-Lattice of.—An X-ray examination of crystals of gold and lead by Bragg's method has been made by L. Vegard.† The gold crystal used was a native one, in the usual form of a thin plate, twinned about an octahedral face. The lead was an exactly

* *Philosophical Magazine*, 1916 (vi.), vol. xxxii. p. 141.

† *Ibid.*, p. 65.

similar crystal, prepared artificially by immersing zinc in a solution of lead acetate. The angles of reflection of both metals agree perfectly with those required for a face-centred cubic lattice. This is the same lattice found by Bragg for copper and by Vegard for silver.—C. H. D.

Hall and Allied Effects.—The Hall coefficients of indium, lithium, molybdenum, tungsten, cerium, tantalum and thallium are found by A. W. Smith * to be of the same order as for copper or silver. The Nernst coefficient is higher in tungsten than in any of the other metals.

In indium and lithium the Hall effect has the direction predicted by the electron theory, but in the other metals it has the opposite direction. The direction of the Nernst effect agrees with the electron theory in indium, lithium, cerium and tantalum, but is opposed to it in molybdenum, tungsten and thallium.

The von Ettingshausen effect has been studied in various alloys, and is found sometimes to decrease continuously, and sometimes to increase to a maximum and then decrease with increasing additions of the second metal.—C. H. D.

Hall and Corbino Effects.—The circular current produced in a disc of metal placed in a magnetic field normal to the plane of the disc when a uniform radial current flows through the metal is known as the Corbino effect, and is shown by A. K. Chapman † to be closely related to the Hall effect, and is independent of the thickness of the disc. In the case of iron, a maximum and minimum effect are observed at certain strengths of field.—C. H. D.

Hardness, Change of, with Temperature.—Experiments by P. Ludwik ‡ using the cone indentation method, the metal to be tested being immersed in cylinder oil (or nitre at high temperatures) heated by an electric resistance coil, show the change of hardness of a number of pure metals with change of temperature. Preliminary experiments showed that the hardness of tin, lead, zinc and aluminium was practically the same, whether the metals were quenched or cooled slowly. In the high temperature experiments, two determinations of hardness were always made, the load in one case being left on for 15 seconds, and in the other for 300 seconds. The short period test gave consistently higher values, so that two hardness-temperature curves were obtained for each metal, these curves converging slightly with increasing temperature.

The curves for tin have a point of inflection between 150° and 200° C., whilst those of bismuth, cadmium, lead, zinc and antimony are regularly convex towards the temperature axis. The hardness of lead diminishes very slowly, and that of antimony very rapidly,

* *Physical Review*, 1916 (ii.), vol. viii. p. 79.

† *Philosophical Magazine*, 1916 (vi.), vol. xxxii. p. 303.

‡ *Zeitschrift für physikalische Chemie*, 1916, vol. xci. p. 232.

with temperature. Aluminium gives a point of inflection between 200 and 300° C. The copper curve (for worked and annealed material) is slightly concave to the axis of temperature. When plotted on the same scale, the curves for several of the metals cross one another, so that the order of hardness of different metals varies with the temperature.

All these metals still have an appreciable hardness at the melting point.—C. H. D.

Luminosity Formulae.—The luminosity L' of a non-black body such as a metal is shown by P. D. Foote* to be given by the relation

$$L' = A' e^{\frac{q}{\theta}} P \left(\frac{\theta' + B}{\theta' + C} \right)^D$$

where A' , q , P , B , C and D are constants, and θ the true absolute temperature. θ' is the "colour temperature" of the metal, given by the relation

$$\frac{1}{\theta'} = \frac{1}{\theta} - P$$

Applying this to tungsten, a mean value of $P = 1.91 \pm 0.05 \times 10^{-7}$ is found experimentally. Further, $p = +0.0000104$, $q = +322$ and $A' = 0.303$. Langmuir's values for the emissivity of tungsten give the melting point of that metal as 3712° abs., whilst the values obtained by Hyde, Cardy and Forsythe give 3660° abs.—C. H. D.

Mercury Particles and the Charge of the Electron.—The behaviour of very minute drops of mercury has been studied by A. Schidlof and A. Karpowicz.† The smallest particles had a mass of about 1.9×10^{-13} gramme, this being less than that of the particles hitherto experimented with for the purpose. They are produced by purely mechanical means, whilst those employed by Ehrenhaft and others, produced by means of an electric arc, have probably a different chemical composition. The final value obtained for the charge on an electron is 4.818×10^{-10} electrostatic units.—C. H. D.

Metallic Vapours, Condensation of.—Interesting experiments by M. Knudsen‡ show that mercury vapour is completely condensed on a clean glass surface cooled in liquid oxygen to -140°C. , the proportion of molecules repelled by the surface being immeasurably small. At a temperature only a few degrees higher, a very appreciable proportion is repelled. When the temperature of the cold surface is -77.5°C. , only about $\frac{1}{5000}$ of the molecules are retained by the glass on their first impact. On the other hand, when a layer of mercury has once been formed, impinging molecules are completely retained.

* *Journal of the Washington Academy of Sciences*, 1916, vol. vi. p. 365.

† *Archives des Sciences physiques et naturelles*, 1916, (iv.), vol. xli. p. 125.

‡ *Annalen der Physik*, 1916 (iv.), vol. l. p. 472.

Similar experiments with zinc, cadmium and magnesium show that at ordinary temperatures, or at -63° , the probability that a molecule will adhere on its first impact is vanishingly small. The deposit is formed uniformly over the whole surface, and not localized on the spot opposite the jet of issuing vapour. In liquid oxygen, the spot is localized, and as the deposit thickens it separates from the glass, giving a dendritic pattern.

There appears to be for each metal a critical temperature, below which impinging particles are completely retained by glass or mica, but above which an appreciable fraction of the molecules is repelled. These temperatures are, for

Mercury,	between -140° and -130° C.
Zinc	} „ -183° and -78°
Cadmium	
Magnesium	
Copper	„ $+350^{\circ}$ and 575°
Silver	above 575°

C. H. D.

Metals, Action of Acids containing Hydrogen Peroxide on.—It is shown by E. Salkowski * that metals which are insoluble, or only attacked with difficulty by ordinary acids are often dissolved quite readily when hydrogen peroxide is added. In the case of hydrochloric acid, the action is due to the formation of free chlorine, so that all metals except those which form insoluble chlorides are dissolved. Mercury is unattacked, no mercuric chloride being formed. With dilute sulphuric acid, copper, silver, mercury, bismuth and nickel are attacked, but not tin, lead, gold, platinum or antimony. Glacial acetic acid with hydrogen peroxide dissolves copper, silver, lead, mercury and bismuth, even when cold, but not tin, gold, platinum or nickel. The author suggests that this solvent may be useful in analysis. [*Note by Abstractor.*—The addition of hydrogen peroxide to nitric acid for dissolving steels is already practised in some laboratories.]—C. H. D.

Metals, Action of Carbon Dioxide on—As carbon dioxide is often purified from traces of oxygen by passing over heated copper, F. von Bacho † has made some experiments to determine whether any carbon monoxide is formed under such conditions. It is found that copper turnings or gauze, freed from hydrogen by ignition in a stream of carbon dioxide, does not react with carbon dioxide at a full red heat, palladium chloride being used as the reagent to detect carbon monoxide. At 1070° C. a slight action occurs, and when the copper melts reaction takes place, and cuprous oxide and carbon monoxide are formed.

The action of carbon dioxide and antimony begins at 830° C., and is well marked at 870° . Carbon monoxide and antimony trioxide are formed.—C. H. D.

* *Chemiker-Zeitung*, 1916, vol. xl. p. 448.¹

† *Monatshefte für Chemie*, 1916, vol. xxxvii. p. 119.

Metals, Colour of Pure.—According to W. I. Baragiola,* copper which has been distilled ten times or more in a high vacuum has only a pale rose colour, whilst the yellow colour of gold becomes lighter under the same conditions. It is suggested that copper in the pure condition may have a light grey colour like that of most other metals.—C. H. D.

Palladium, Catalytic Activity of.—The catalytic oxidation of hypophosphite solutions by palladium has been studied by A. Sieverts and E. Peters.† Palladium black is always active, however prepared. The ignited sponge is active, but much less so, whilst foil and wire are inactive, even if charged with hydrogen, but if oxidized the hypophosphite reduces the surface layer and the metal becomes active. Electrolytically deposited palladium gradually becomes inactive in contact with hypophosphite solutions. Colloidal palladium is much more active even than the black.

The effect of different preparations of colloidal palladium and platinum on the catalytic reduction of organic compounds has been studied by J. Boeseken.‡—C. H. D.

Palladium, Influence of Hydrogen on Magnetism of.—The magnetic susceptibility of palladium is shown by H. F. Biggs § to be diminished by hydrogen absorbed by the metal. The susceptibility-gradient is practically independent of the magnetic field and of the actual volumes of hydrogen. If the gradient remains the same until saturation is reached, saturated palladium should be actually diamagnetic, but the experiments were not carried as far as this.—C. H. D.

Photo-electric Potentials.—Experiments with magnesium, aluminium, zinc, iron, tin and copper by A. E. Hennings and W. H. Kadesch || show that the electrons released from a given surface by light of a given frequency have energies which do not exceed a given finite value. All of these metals give the same maximum positive potential, provided that the surfaces have been newly scraped in a vacuum. Retarding films are gradually formed on all the surfaces, most rapidly on magnesium.

A second paper by W. H. Kadesch and A. E. Hennings ¶ shows that when experimental errors are eliminated, the slope of the frequency potential curve is independent of the nature of the illuminated surface, and is in agreement with Einstein's theory.

The effect of occluded gases on the photo-electric effect has been examined by R. J. Piersol, ** who finds that a maximum effect due to

* *Schweizerische Apotheker-Zeitung*, 1915, vol. liii. p. 477.

† *Zeitschrift für physikalische Chemie*, 1916, vol. xci. p. 199.

‡ *Receuil des travaux chimiques des Pays-Bas*, 1916, vol. xxxv. p. 260.

§ *Philosophical Magazine*, 1916 (vi.), vol. xxxii. p. 131.

|| *Physical Review*, 1916 (ii.), vol. viii. p. 209.

¶ *Ibid.*, p. 221.

** *Ibid.*, p. 238.

gases is superimposed on the intrinsic effect. It is the emission rather than the absorption of gases which is responsible for the effect. In the case of metals of high melting point, heating electrically *in vacuo* ultimately drives off the gas, and the superimposed effect disappears. The metal then becomes more sensitive than before cleaning.

In the case of the metals lithium, sodium and potassium, W. H. Souder * finds that surfaces freshly cut *in vacuo* are active, and a maximum or selective effect is observed. This is attributed to some surface condition.

The effect of gases is not considered, and the low melting point would prevent the expulsion of occluded gas by heat.

The variation of the photo-electric current with the angle of emission and the thickness of the emitting film has been examined by W. Gardner,† the films being deposited on quartz by cathodic sputtering.—C. H. D.

Photo-electric Properties.—Contrary to the statements of Pohl and Pringsheim, G. Wiedmann ‡ finds that the photo-electric sensitiveness of potassium falls to as little as 1 per cent. of its original value when the metal has been repeatedly distilled so as to remove dissolved gases as completely as possible. The selective photo-electric action disappears when the gases are removed, but reappears when a weak discharge is passed through the cell, the potassium being the cathode.—C. H. D.

Platinum, Emission Currents from Hot.—It has been found that when a fresh platinum wire is positively charged and heated in a vacuum, the relation between current and E.M.F., allowing for decay with time, is approximately linear. As saturation might be expected to occur at a small potential, O. W. Richardson and C. Sheard § have investigated the matter further, and suggest that saturation is prevented by the impact of ions on the negative electrode. The experiments are not yet regarded as decisive on this point.—C. H. D.

Platinum, Presence of Nickel in Native.—In the course of an examination of the native platinum recently discovered in Spain, S. Pina de Rubies || has observed the presence of nickel in the metal. Only one previous analysis of native platinum shows the presence of nickel, this being of a magnetic platinum of Nischne-Taguisk, containing 0.75 per cent. of nickel. An examination of native platinum from Russia, America and Spain by means of the spectroscope now shows that nickel is always present, in quantities which are capable of being estimated. Thus the metal from Kitlim (Russia) gives a spectrum indicating 0.1 per cent. or more of nickel. The proportion appears to increase with that of iron.—C. H. D.

* *Physical Review*, 1916 (ii.), vol. viii. p. 310.

† *Ibid.*, p. 70.

‡ *Berichte der deutschen physikalischen Gesellschaft*, 1915, vol. xvii. p. 343.

§ *Philosophical Magazine*, 1916 (vi.), vol. xxxi. p. 497.

|| *Archives des Sciences physiques et naturelles*, 1916 (iv.), vol. xli. p. 475.

Platinum, Recovery of Scrap.—For the conversion of scrap platinum into chloroplatinic acid, J. B. Tingle and A. Tingle* recommend alloying the platinum with zinc by fusion under borax. After dissolving out the zinc with hydrochloric acid, the platinum remains as a black powder, which is readily soluble in a mixture of hydrochloric and nitric acids. Some zinc is also present, so the platinum is purified either by precipitation with a rod of metallic zinc or as sulphide, and is then redissolved.—C. H. D.

Platinum, Volatilization of.—Further experiments on the volatilization of platinum have been made by G. K. Burgess and R. G. Waltenberg.† Several platinum crucibles of different degrees of purity have been heated at 700°, 1000°, and 1200° C. In all cases the loss on heating is negligible below 900°, even when as much as 3 per cent. of iridium is present. Below this, crucibles containing iron even gain in weight, owing to the iron diffusing to the surface and then oxidizing. At high temperatures this gain due to iron partially balances the loss due to other metals. Rhodium diminishes, and iridium increases, the loss of weight. Extraction with acid after heating causes a further loss, which is sometimes large. Silica may be taken up at or above 1000° C. if the platinum is heated near to porcelain, although not in contact with it, and in an oxidizing atmosphere. The loss on first heating is erratic, but afterwards the loss on each heating to the same temperature is approximately constant.—C. H. D.

Platinum Films, Photo-electric Effect in.—Measurements by J. Robinson‡ show that the photo-electric current from a thin platinum film increases gradually with the thickness of the film at first, then very suddenly, after which it falls. The light absorbed by the film increases uniformly with its thickness. The photo-electric current for unit intensity of light absorbed therefore shows a strong maximum at a thickness of about 10^{-7} cm.—C. H. D.

Radio-Lead, Density of.—Lead from pure crystals of Norwegian cleveite is found by T. W. Richards and C. Wadsworth§ to have a density at 19.94° C. of 11.273. This is lower than that of ordinary lead (11.337). It may be assumed to represent the pure isotope, derived from uranium. The atomic volumes of the two isotopes are identical.—C. H. D.

Rarer Metals, Metallurgy of.—The present position as regards the production and possible uses, &c., of a number of metals which

* *Journal of the Society of Chemical Industry*, 1916, vol. xxxv. p. 77.

† *U.S. Bureau of Standards, Scientific Paper No. 280*, 1916.

‡ *Philosophical Magazine*, 1916 (vi.), vol. xxxii. p. 421.

§ *Journal of the American Chemical Society*, 1916, vol. xxxviii. p. 1658.

may be classed as the "rarer metals" is discussed at some length by J. W. Richards.*

Thirty years ago aluminium would have been included as one of the rarer metals. In 1886 it was selling at \$10 per pound although its ores were exceedingly common. One ton of bauxite containing $\frac{3}{16}$ ton of aluminium would be purchased for \$5, whilst the $\frac{3}{16}$ ton of aluminium was being sold for \$3000 wholesale. So attractive was the problem of cheapening the production of this metal that in less than ten years the market price had fallen to $\frac{1}{10}$ of the above figure.

Silicon furnishes another example. Silica is the most abundant and cheapest material in nature, yet in 1900 silicon was selling as a chemical curiosity at over \$100 per ounce. At the present time, thanks to the electric furnace, 10 cents per pound is a good market price for the metalloid, which is often sold by the car load.

Among the metals at present of high price but which by improved metallurgical processes might be made very cheaply are beryllium, boron, magnesium, calcium, strontium, zirconium, molybdenum, barium, titanium, chromium, and cerium.

Beryllium.—The principal ore beryl, looking like massive green quartz, is abundant in some localities. The beryl crystals of Ackworth, N.H., are sometimes as large as a barrel and are quarried like felspar.

Composition per cent.:

SiO ₂	.	.	.	.	.	.	.	.	.	.	.	67.0
Al ₂ O ₃	.	.	.	.	.	.	.	.	.	.	.	19.0
BeO	.	.	.	.	.	.	.	.	.	.	.	14.0

Up to the present, isolation of the metal has only been accomplished by:

- (1) Reduction of a halogen salt by sodium or potassium (Bussy, Wöhler, Debray, Menier, Nilson and Pettersen, Kruss and Morah);
- (2) Electrolysis of double halogen salt of beryllium and sodium or potassium (Borchers, Warren, Lebeau, Liebmann).

These methods are tedious and costly. It is not to be expected that beryllium can be made cheaply until the direct electrolysis of the oxide dissolved or suspended in a more stable melted salt is mastered, as was done in the case of aluminium.

The present-day price is \$300 per ounce.

Lebeau has produced beryllium bronzes by reducing directly in the electric furnace a mixture of beryllium oxide and copper oxide with carbon. 0.5 per cent. renders copper hard and sonorous: 1.5 makes it yellow and 5 per cent. gives a fine golden yellow bronze. Beryllium is white, malleable, and permanent in the air. Its specific gravity is 1.64. Valuable use might be made of the metal in the production of light as well as heavy alloys.

Its specific heat is the highest of any useful metal.

Magnesium.—The metallurgist has been coquetting with magnesium for half a century. The oxide is cheap and abundant. To prepare by

* *Metallurgical and Chemical Engineering*, July 1916, vol. xv (No. 1.), pp. 26-31.

tedious methods the anhydrous double chloride and then electrolyze it much as Matthiesen did fifty years ago is nearly all that can be said with certainty of its present metallurgy. Whereas the oxide costs a few cents per pound the metal is scarce and sells for about as many dollars. Present methods of production have been summarized by W. M. Grosvenor, who places the actual cost of the metal at one dollar per pound, leaving over ninety cents per pound for cost of extraction. The point of attack should be to reduce the oxide direct by electrolysis. Reduction by carbon at 1800° to 2000° C. is possible. Magnesium forms no carbide at high temperatures.

The metal is light and valuable for light alloy manufacture. It is a more powerful deoxidizer than aluminium and might with advantage replace that metal for deoxidizing copper, brass, bronze, nickel, monel metal, &c.

Calcium, Strontium, and Barium.—A trio of interesting metals common enough in nature, but all scarce and of high price for lack of efficient and cheap methods of production and whose specific properties and particular uses require thorough study. Calcium, the best known of the three, at present sold at a few dollars per pound, is fairly successfully and cheaply prepared by electrolysis of the fused chloride. Strontium and barium cost several dollars per ounce.

Calcium-silicon-aluminium alloy has already found application as a deoxidizing agent in steel. The addition of calcium to the light stiff aluminium alloys is worthy of attention and has not been investigated.

Boron.—Cheap and abundant in its compounds yet almost unknown as an element, this metalloid is quoted at several dollars per ounce, yet there are possibilities of its production at something over 25 cents per pound. Chemically the reduction of the oxide does not appear to be of great difficulty. Recently, Weintraub has decomposed the chloride by hydrogen in a high tension arc and obtained purer boron and in greater quantity than any previous worker. He melted it, at 2000° to 2500° C., in a boron nitride crucible under pressure of its own vapour. It possesses extraordinary electrical properties useful for many contrivances enumerated by Weintraub.* In metals and alloys boron can act chemically as a refining agent, removing oxides, &c., whilst in larger quantity it alloys with them. Boron, or even the sub-oxide, added to molten copper, enables perfect castings to be obtained of practically 100 per cent. conductivity. Improved and more certain methods of getting boron into copper are needed.

Chromium.—Common and abundant in its ores, rare and expensive as a metal. Pure chromium, carbon free, is produced only by reduction of the oxide by aluminium, and commands 75 cents per pound. The use of the pure metal is limited by the high cost of its production and lack of knowledge of how to handle it. The use of chromium in steel is rapidly extending to all varieties of extra hard and high-speed

* *Transactions of the American Electro-chemical Society*, 1909.

material. Chromium electroplating is white and durable but the technique of the process has not been mastered. Chromium-cobalt alloys have been made which have some of the remarkable properties and uses of high-speed tool steel (Stellite alloy of Haines). This is an excellent example of totally unexpected and valuable properties discovered by systematic work. Pure chromium is necessary for the manufacture of these alloys and not ferro-chrome.

Titanium.—One can buy titanium metal at about the price of silver; the methods of production of the pure metal and its prospective uses are still in the future. In addition to the titanium treatment of steel a speciality has been made in America of titanium-treated aluminium bronzes, ordinary bronzes and brasses.

Molybdenum.—The selling price of the metal is \$2 per pound. The principal need of the industry is a better utilization of its sources of raw material. The use of molybdenum in steel might be increased. The wire is useful in electric resistance furnaces. It resists the alloying action of many liquid metals even at very high temperatures.*

Zirconium.—The oxide has recently been found in considerable abundance, and is being used in large quantities as a refractory material on account of its high melting point, 2000° C., high resistance to all kinds of slags, low thermal conductivity and coefficient of expansion.

The metal is almost an unknown quantity. It melts at 1500° C. and is hard enough to scratch quartz. \$5 per ounce is asked for it.

Cerium.—There is a peculiar interest attaching to this metal and its close associates owing to the fact that hundreds of tons of fairly rich cerium material are lying on the waste heaps outside the incandescent mantle factories. An immense amount of work has been done on the production of mixed metal and purer cerium. Alloyed with 30 per cent. of iron a material is obtained with remarkable spark-giving properties when scratched. Addition of cerium to aluminium has been suggested by Borchers to improve its properties. Previous to the European war, over 3000 workers were employed in America in the pyrophoric alloy industry.—S. L. A.

Selenium, Resistance of Crystalline.—Crystals of metallic selenium, according to K. J. Dieterich, † show a falling electrical resistance with increasing temperature, with a small increase between 0° and 50° C. The sensitiveness to light varies very little with temperature, but a slight maximum occurs between 30° and 50° C. If the recovery be regarded as caused by the recombination of negative electrons with positive residues, the coefficient of combination decreases with increasing temperature.—C. H. D.

Sherardizing Process.—The coating of iron and steel with zinc by the process known as “Sherardizing” is discussed at length, with

* C. G. Fink, *Transactions of the American Electro-chemical Society*, 1910.

† *Physical Review*, 1916 (ii.) vol. viii. p. 551.

an account of the experiments and results of a number of workers, by O. W. Storey.* Numerous references are given. The following conclusions are drawn :—

1. The exact composition of the zinc-iron alloys formed in sherardizing cannot be known until the solubility relations of the two metals have been determined.

2. The coating consists of definite layers of iron-zinc compounds.

3. The iron content of the sherardized coating is a function of the temperature.

4. Sherardizing is principally a contact action made possible by the formation of inter-metallic compounds.

5. Sherardizing, when carried out properly, gives a coating that is highly resistant to corrosion.

6. A zinc dust having a high metallic content will give the best coating.

7. Sherardizing should be carried out at the lowest temperature economically possible to secure a low iron content in the coating.

8. A high iron content in a sherardized coating is detrimental to its weathering properties.

9. The copper sulphate test gives excellent results for daily furnace control tests.—S. L. A.

Silver, Absorption of Gases by.—The sources of error in the determination of atomic weights when silver is used as a standard have been further investigated by P. A. Guye and F. E. E. Germann.† The metal is often fused in hydrogen, the gas being bubbled through the molten silver. Although hydrogen is practically insoluble, other gases which may be present, especially carbon monoxide, are very appreciably soluble in silver, the quantity being sufficient to account for the observed variations. In determining the quantity of gas, the silver is converted into iodide by the action of iodine free from gases, the gas evolved being collected in an apparatus of special design.—C. H. D.

Silver, Spitting of.—The spitting of crude silver which has been precipitated from solutions containing iron sulphate has been investigated by W. Stahl.‡ The effect has been attributed to sulphur dioxide, but this gas is quite insoluble in molten silver. It reacts with silver, however, according to the equation $4\text{Ag} + 2\text{SO}_2 \rightleftharpoons \text{Ag}_2\text{SO}_4 + \text{Ag}_2\text{S}$, or in presence of oxygen $4\text{Ag} + 2\text{SO}_2 + 2\text{O}_2 \rightleftharpoons 2\text{Ag}_2\text{SO}_4$. The sulphate does not dissociate until 1080°C . is reached, and when silver is gently melted the fused sulphate remains on the surface as a slag. At higher temperatures it dissociates, yielding sulphur dioxide and oxygen :

* *Metallurgical and Chemical Engineering*, June 1916, vol. xiv (No. 12), p. 683.

† *Journal de Chimie Physique*, 1916, vol. xiv, p. 204.

‡ *Metall und Erz*, 1916, vol. xii, p. 501.

$\text{Ag}_2\text{SO}_4 = 2\text{Ag} + \text{SO}_2 + \text{O}_2$, and this oxygen dissolves in the silver, causing spitting when the metal solidifies.—C. H. D.

Specific Inductive Capacity.—An attempt to calculate the specific inductive capacities of metallic atoms is made by F. Sanford,* calculating from the charges of the ions in electrolysis and from the refraction constants.—C. H. D.

Thomson Effect in Incandescent Wires.—According to Walter König† when a loop of platinum wire is heated to incandescence by an electric current, and the lower part is immersed in water, the level at which incandescence ceases is different on the two sides. This is attributed to the Thomson effect. In order to determine the relative shares of the Thomson and Peltier effects when different metals are used, two similar platinum wires are fixed vertically in an evacuated glass vessel. Both are attached to the same mass of copper at the top, but at the lower ends one is cooled by attachment to a block of iron, and the other by a similar block of nickel. These two metals give thermo-electric effects with platinum of similar magnitude but opposite sign, the current at the cold junction passing from platinum to nickel but from iron to platinum. The Thomson effect in platinum is negative, so that heat is absorbed when the current passes towards the cooling block. Thus with iron the Thomson and Peltier effects should co-operate, in nickel oppose one another. The heating current was passed in the order iron, platinum, copper, platinum, nickel. The temperature of each wire is determined at several different levels. The results show that the Peltier effect is very small in comparison with the Thomson effect under such conditions.—C. H. D.

Tin, Specifications of.—In a paper submitted to the American Society for Testing Materials, Messrs. L. Addicks and W. A. Cowan‡ discuss the purity of various grades of tin, and suggest a specification for best quality tin. Until recently the purity of tin depended largely on that of the original tinstone from which it was obtained, but the introduction of electrolytically refined tin has made it possible to put on the market a purified product obtained from foul bullion.

The impurities in tin, the most important of which are antimony, arsenic, bismuth, copper, iron, lead and zinc, may cause trouble in a variety of ways—by poisoning, as in the case of pipe and tin cans; by impairing fluidity, causing excessive consumption in coating and by making solder difficult to apply; by fouling an alloy and spoiling its appearance, by impairing the ductility in alloys which have to be worked, such as bronze or Britannia metal; by causing local galvanic

* *Physical Review*, 1916 (ii.), vol. viii. p. 89.

† *Physikalische Zeitschrift*, 1916, vol. xvii. p. 227.

‡ *American Society for Testing Materials*, 1916, p. 59.

action and possibly "tin-pest"; and by affecting the melting point of fusible alloys.

They suggest as the maximum allowances for electrolytically refined tin :

Metal.	Per Cent.
Lead	0.04
Copper.	0.02
Iron	0.05
Arsenic	0.05
Antimony	0.02
Zinc	0.05

D. H.

Vanadium, Preparation of.—A convenient laboratory method of preparing vanadium is described by R. Edson and D. McIntosh.* A flask containing some vanadyl chloride is provided with a stopper which carries inlet and outlet tubes for the passage of a stream of dry hydrogen, and also with two copper leads connected by a thin platinum wire. The wire is raised to incandescence by passing an electric current, and the vanadyl chloride is decomposed by contact with it, pure vanadium being deposited in a metallic film.—C. H. D.

Zinc, Notes on.—The sources of commercial zinc, its impurities, properties and chief alloys are described by H. Best.†

The impurities dealt with are lead, iron and cadmium, which all interfere with the satisfactory application of zinc.

The worst impurity is lead, which, if in a percentage exceeding 2 or 2.5 per cent., in addition to its injurious effects in alloys, renders the zinc unsuitable for galvanizing, as the lead is easily dissolved by most soft waters, thus exposing the surface of the galvanized metal and hastening corrosion.

The following physical properties, &c., are described, viz.:—hardness, tenacity, frangibility, malleability, ductility, expansion, specific gravity, specific heat, thermal conductivity, electrical conductivity, electrical resistance, thermo-electric power, inflammability, latent heat, atomic weight, equivalent, melting and boiling points, crystalline form, weight per cubic foot, fracture, contraction, weight of castings, foundry uses and chief alloys.—F. J.

* *Transactions of the Royal Society of Canada*, 1915 (iii.), vol. ix. p. 81.

† *Mechanical World*, August 1916, vol. lx. p. 64.

II.—PROPERTIES OF ALLOYS.

Alkali Amalgams. Density of.—In view of erroneous statements in many text-books, J. R. Withrow * points out that the solid amalgams of sodium, potassium and lithium are lighter than mercury, and float on the surface of the dilute liquid amalgams.—C. H. D.

Alloys to withstand Internal Air Pressure.—S. D. Sleeth † gives an account of the preparation of bronze and brass castings which have to withstand internal air pressure. The main factors which demand care are the design of the casting and pattern, and the regulation of the alloy in the furnace and during pouring. Uniformity of cross-section should be obtained if possible in order to prevent drawing at heavy portions, and if necessary chills should be introduced into the mould. These should where possible be placed in a vertical position in order to prevent the metal “kicking off” these surfaces. Valve seats, &c. should be clean and the moulds must be so designed that loose sand can collect in unimportant parts. A large pouring gate should be used and should be placed close to the pattern, while the gate leading to the pattern should be sharply reduced at the point of entry.

The following alloys have been found satisfactory.

Metals.	No. 1 Alloy.	No. 2 Alloy.	No. 3 Alloy.
	Per Cent.	Per Cent.	Per Cent.
Copper . . .	72.50	82.00	83.00
Tin	1.75	7.50	11.50
Zinc	19.25	4.75	4.00
Lead	6.50	5.75	1.50

No. 1 alloy is recommended for ordinary castings and Nos. 2 and 3 alloys for use with high pressures.

The pouring temperature should not be high nor should the metal be allowed to soak in the furnace, as failure to observe these conditions will result in porous castings being obtained.

It is stated that aluminium, even in small quantities, and, to a lesser extent, antimony and iron, are very dangerous and give castings which are porous under pressure.‡—D. H.

Amalgams, Volume Changes in.—Certain anomalies in the change of volume of bismuth amalgams with temperature are attributed by J. Würschmidt § to the existence of two allotropic modifications of

* *Journal of Physical Chemistry*, 1916, vol. xx, p. 528.

† *Transactions of the American Institute of Metals*, 1917.

‡ See also Carpenter and Edwards, *Proceedings of the Institution of Mechanical Engineers*, 1910, p. 1597.—Ed.

§ *Berichte der deutschen physikalischen Gesellschaft*, 1914, vol. xvi, p. 799.

bismuth, with a transition point at 75°. The transformation on heating takes place with considerable contraction.

After repeated heating and cooling the anomalies disappear, and this is attributed to segregation of the components. By heating strongly the amalgam again becomes homogeneous, and the anomalies reappear.—C. H. D.

Arsenides, Synthesis of.—In an attempt to prepare definite metallic arsenides, A. Beutell and F. Lorenz * have heated naturally occurring arsenides in a vacuum until constant in weight, and have also heated both the residues thus obtained and the pure metals in an atmosphere of arsenic. In the case of cobalt, the following definite compounds are recorded, the order being such that the range of stability for each arsenide is at a higher temperature than those which precede it: CoAs , Co_2As_3 , CoAs_2 , Co_2As_5 , CoAs_3 . Only two nickel arsenides are obtained in this way: NiAs and NiAs_2 .

(This method cannot be depended on for the determination of the formulae of compounds, the residues thus obtained not being necessarily definite substances.)—C. H. D.

Brass, Seasoning Cracks in.—W. Arthur † describes a number of interesting cases of cracking of brass articles on storage. This phenomenon, which is well known especially to makers of cartridge cases, has, as yet, not been satisfactorily explained. The cracking is generally intercrystalline in character and the author suggests that it is due to an actual recrystallization of the metal, though there is no direct proof of this. It would be thought that if this were so, annealing in the ordinary way would produce cracking, but it is suggested that as season cracks begin on the surface and extend inwards, any contractions due to a change in volume are counterbalanced by the expansion due to heating. Corrosion has been suggested as a possible cause, but little evidence can be found to support this view, while it has proved equally impossible to attribute the cracking to any impurity. The author's suggestion is that in the drawing operations the metal is considerably distorted and "cold-worked" with the production of large quantities of amorphous metal, and a slight increase in volume occurs. When the metal attempts to recrystallize, the decrease in volume causes a condition of acute internal stress which results in the final rupture of the metal. Nearly all cases of cracking are found in those areas in which the metal has been greatly overworked, as, for example, in the heads of cartridge cases, which are subjected to an operation which, as usually carried out, produces the most severe internal stresses.—D. H.

* *Centralblatt für Mineralogie*, 1916, pp. 10, 49.

† *Transactions of the American Institute of Metals*, 1917.

Bronzes, Ancient Peruvian.—An elaborate memoir by C. H. Mathewson describes the metallographic character of a large number of ancient objects of bronze from Machu Picchu, in Peru, collected by the National Geographic Society's Expedition of 1912. Analyses of thirty-three of the specimens have been made, and show that the composition was not regulated by the use to which the object was to be put, but was irregular. One mass consists of practically pure tin, proving that this metal was known in the elementary form to the Incas. In the bronzes, the tin varies from 3 to 10 per cent., one single object having 13.45 per cent. Sulphur is often high, varying from a trace to 0.44 per cent., but other metals are only present in very small proportions, the bronzes as a whole being remarkably pure. This suggests that they have been made by alloying copper and tin, and not by smelting mixed ores, which would be sure to result in the presence of arsenic and other impurities. Modern concentrates from Peru containing both copper and tin are only smelted with great difficulty. On the other hand, native copper and stream tin are known to occur in the region. Owing to the absence of zinc and phosphorus the castings are frequently unsound.

As sections have been cut through many of the objects, it is possible to trace the methods by which they have been reduced to shape, the effect of cold-working and of subsequent reheating being clearly visible in many of the structures. Holes, where present, appear to have been cast in the metal, and not drilled. The structures of the various objects are described in detail, and an attempt is made in each case to trace the process of manufacture, sections being cut for this purpose, and if necessary subjected to heat treatment.

The author also discusses in some detail the general question of the relation between the growth of crystal grains on annealing, the temperature of annealing, and the amount of cold working to which the metal has been previously subjected. The theories of deformation are also discussed critically.—C. H. D.

Conductivity in Liquid State.—The conductivity of liquid amalgams has been calculated by F. Skaupy † on the assumption that for a given concentration of electrons the conductivity is inversely proportional to the viscosity. The results are not very satisfactory. Data are also given for calculating the dissociation of mercury. Liquid alkali metals are probably highly dissociated. The author has been unable to prove any transport of dissolved metals by a current passing through liquid amalgams.—C. H. D.

Copper Alloys. Notes on.—J. Horner ‡ discusses the difficulties of producing pure copper castings and the employment of deoxidizers. He states that the oldest alloys, the bronzes, are produced to-day much

* *American Journal of Science*, 1916 (iv.), vol. xl, p. 525.

† *Berichte der deutschen physikalischen Gesellschaft*, 1916, vol. xviii, p. 252.

‡ *Mechanical World*, September 1916, vol. ix, pp. 113 and 128.

in the same manner as they have been produced since the method of alloying the separate metals was first discovered. Practical progress in bronze manufacture has been mainly due to the discovery of the influence of other elements, e.g. phosphorus, boron, manganese, iron, magnesium and aluminium. The three most successful alloys are phosphor-bronze, manganese-brass and aluminium-bronze. A review of ancient methods as indicated by neolithic remains is given.

The functions of copper, tin, zinc and phosphorus in modern bronzes are discussed, and also those of lead. Beyond 3 or 4 per cent., lead is liable to cause trouble, the risk increasing with the mass of the casting and pouring temperature. The improvement produced in a bronze by re-heating and quenching is attributed to the existence of a fusible constituent in the bronze which is, by this treatment, re-melted and caused to solidify quickly. [The true explanation is the conversion of alpha and delta eutectoid to beta solid solution at 500° C. and retention of beta by quenching.—*Note by Abstractor.*]

The author refers to eutectoid as eutectic, stating that the coarser this constituent the greater the weakness and permeability to water under pressure. The presence of arsenic is regarded as undesirable, the separation of larger quantities of eutectoid being associated with its presence above 0.25 per cent.

The properties of copper-zinc alloys are discussed. For very exact specifications, correct proportions of constituent metals are essential. If incorrect, chemical compounds, &c., may be formed, injuring the alloy for the particular functions which it is required to fulfil. The foreign materials associated with bought scrap are mentioned and the melting of such scrap into ingots advocated. The use of charcoal and of fluxes for impure scrap, e.g. borax, glass, rock salt and sal-ammoniac is discussed.

The functions of bearing-alloys are considered and the following formulae given :—

	Per Cent.	Per Cent.
Copper.	79	73
Tin	10	6
Lead	10	18
Phosphorus	1	nil
Ferro-Manganese	nil	3

The difficulties in making alloys with high lead contents without segregation are emphasized. Reference is made to Professor Goodman's work on the influence of impurities in bearing-alloys.

Manganese-brass is described and its principal value claimed as being its resistance to corrosion. Hints on melting and mixing are given. In castings, the gates should be large, and bottom-running adopted where possible; skimming-gates and risers are helpful.

Nickel-brass (German silver) is found to undergo such great shrinkage that the runners should contain as much metal as the casting. The mould should be of open sand and thoroughly vented. Various ways of mixing copper, nickel and zinc are discussed.—F. J.

Copper-Antimony Alloys. (a) *Electric Conductivity and Hardness.*

—According to N. Kurnakoff, P. Nabereznoff and W. Ivanoff* the copper-antimony alloy Cu_2Sb is characterized on the isotherms of electric conductivity from 10° to 600° by a sharply defined maximum, and the temperature-coefficient of the electric resistance, (α), according to N. T. Stepanoff's rule, is near to that of pure metals. Between 25° and 100° the coefficient $\alpha = 0.00496$.

The minimum on the curves of electric conductivity and of the temperature-coefficient due to the solid solutions β_1 (74 to 80 atomic per cent. of copper) and β_2 (67 to 81 atomic per cent. of copper) were known heretofore as polymorphic forms of the definite compound Cu_3Sb . But these curves in the region 10° to 600° are uninterrupted slightly bent lines and do not indicate the existence of the "singular" point at the atomic ratio $\text{Cu} : \text{Sb} = 3 : 1$ (75 atomic per cent. of copper). For the interval 25° to 100° the temperature-coefficient of the resistance varies between the limits 0.00022 and 0.00112.

Thus the study of the electric conductivity does not confirm the existence of the definite compound Cu_3Sb . The detailed thermal and micrographic observations fix the presence of new polymorphic solid solutions— γ_1 and γ_2 (80 to 87 atomic per cent. of copper)—which separate from solid solution β_1 and β_2 .

At the limiting concentration of the phase γ_1 (81 atomic per cent. of copper) lies the maximum hardness (299 kg. per sq. mm., according to Brinell's method) and the minimum temperature-coefficient of the electric resistance ($\alpha = 0.00014$) for the copper-antimony alloys.

(b) *Physico-chemical Analysis.*—The comparison of the diagram of fusibility, microstructure, hardness and electric conductivity of the copper-antimony system shows clearly, according to N. Kurnakoff and K. Beloglasoff,† the existence of the "singular" point of the copper-antimony alloy Cu_2Sb . But another phase is the solid solution β_1 (74 to 80 atomic per cent. of copper) which is transformed at 410° into the phase β_2 . The substance β_2 , stable above 410° , is regarded by many investigators (Stead, Bajkoff, Carpenter) as a definite compound Cu_3Sb (75 atomic per cent. of copper) giving solid solutions with excess of both its components (67 to 84 atomic per cent. of copper).

However, the detailed observations with Kurnakoff's pyrometer lead to the deduction that the maximum point on the freezing point curve of this substance lies about 72 atomic per cent. of copper and does not correspond to the ratio 3 : 1.

In accordance with this the isotherms for electrical conductivity at the temperature 410° to 600° also fail to show the "singular" point within

* *Journal of the Russian Physico-chemical Society*, pt. 2, Proceedings, 1916, vol. xlviii, p. 701.

† *Journal of the Russian Physico-chemical Society*, Proceedings, pt. 2, 1916, vol. xlvii, p. 700.

the limits of the existence of the β_2 phase. Similar relations are observed in the electric conductivity and hardness diagrams of the β_1 phase (74 to 80 atomic per cent. of copper) representing the product of transformations of the substance β_2 below 410° , and stable at the ordinary temperature.

From the investigation of the diagrams of properties the authors conclude that β_1 and β_2 are the compounds of variable composition and propose to name α and β "Lechatelite," in honour of Professor Le Chatelier, the first investigator of the fusibility diagrams of the copper-antimony alloys.—N. K.

Gallium-Indium Alloy.—A liquid alloy of gallium and indium is described by P. E. Browning and H. S. Uhler.* It was first obtained in the form of globules, closely resembling mercury, on the surface of a residue containing lead from the distillation of zinc. The alloy has a sp. gr. 5.95 at 20°C ., and melts about 29.5°C ., but remains liquid for hours even at 0° . If heated in a vacuum at or over 1600°C ., the indium may be completely removed by distillation, gallium remaining in the silica tube. The alloy is only slightly attacked by the common acids or by alkali hydroxides, even on warming.—C. H. D.

Hardening, Change of Volume of Alloys on.—M. Oknow † has investigated the change of volume of several copper alloys at the eutectoid transformations.

For the investigation samples of 30 to 50 gr. were prepared and the specific gravity determined by the method of weighing in water. This determination was made for each specimen many times after different thermal treatment.

The following systems were examined by this method.

(1) The alloys of Cu-Al, lying near the two eutectoids—the one containing about 12 per cent. of aluminium and consisting of the mixture $\alpha + \gamma$, obtained from the breaking up of the solid solution β at 567° , and the others containing about 22.5 per cent. of aluminium consisting of the mixture $\epsilon + \gamma$, obtained from the breaking up of the solid solution δ at 570° . These results show that the first transformation $\beta \rightarrow \alpha + \gamma$ is accompanied by a visible increase of volume (about 0.6 per cent.). In the case of the second transformation $\delta \rightarrow \epsilon + \gamma$, the author was unable to detect any change of volume on hardening.

(2) In the system Cu + Sn the eutectoid $\alpha + \delta$ was examined. This also manifested a visible increase of volume on hardening (about 0.3 per cent.), though it was less than in the system Cu + Al.

(3) In the system Cu + Zn, the alloys near the eutectoid at 57 per cent. of zinc, consisting of the products of the breaking up of the solid

* *American Journal of Science*, 1916 (iv.), vol. xli. p. 351.

† *Revue de la Société Russe de Métallurgie*, 1915, vol. vi. p. 442.

solution β ($\beta \rightarrow \alpha + \gamma$, at 470°), and the alloys near the other eutectoid at 72 per cent. of zinc consisting of the products of the breaking up of the solid solution δ ($\delta \rightarrow \gamma + \epsilon$ at 450°) were examined. In these alloys the breaking up of the solid solution β is accompanied by a decrease of volume (about 0.4 per cent.) and the breaking up of the solid solution δ by an increase of volume (about 0.4 per cent.).

On examining the structures of the alloys it was found that in all cases, when the breaking up of the eutectoid is accompanied by the transformation of volume, a laminated structure is obtained which is very similar to the lamellar pearlite in steel.

It was similarly observed that in the hardened state the eutectoid structure of the majority of the alloys investigated has the typical martensitic structure which is obtained in hardened steel.

From this the author concludes that both the pearlitic and the martensitic structures are the result of internal stresses, which are induced by the changes of volume at the critical points.—N. K.

Light Aluminium Alloys.—A dissertation on this subject is published by H. Schirmeister.* All the alloys were prepared in the same gas furnace, in quantities of 800 to 900 grammes, and cast in iron chills as plates 25 mm. thick, which were then rolled down in a mill, annealing repeatedly, and finally cold-rolling to a thickness of 1.3 to 1.5 mm. The test-pieces were cut from these sheets, annealed for 2 hours at 300° to 350° C. in a muffle, cooled in air and tested after a few days' interval.

The alloys with zinc increase in tenacity and hardness with increasing zinc up to 28 per cent. The ductility falls at first, rises to a maximum at 12 to 14 per cent., and then falls more rapidly. Alloys with 12 to 14 per cent. of zinc give the same elongation as pure aluminium, with about twice the tensile strength in the annealed state.

Magnesium, in very small quantities, makes the grain of aluminium finer, larger quantities produce a coarser grain, until 4 per cent. is reached, when it is again fine. Shrinkage is a minimum at 3 or 4 per cent. Between 3 and 10 per cent. the alloys tarnish rapidly. The plates may be rolled hot up to 6 or 7 per cent. of magnesium, beyond this they are brittle. The tensile strength and elongation are very little affected up to 1.5 per cent. The conclusion is drawn that the addition of magnesium to aluminium is of very little value.

Copper has little effect in reducing piping and shrinkage, but refines the grain. Alloys containing up to 12 per cent. may, with care, be rolled hot. The tensile strength rises rapidly up to 4 per cent., then more gradually, the elongation pursuing an exactly opposite course. The best rolled product is obtained with 3 to 4 per cent. of copper; the best castings with 10 to 15 per cent.

Nickel increases the strength considerably, but the fracture becomes

* *Stahl und Eisen*, 1915, vol. xxv. pp. 650, 873, 996.

very coarse when the nickel percentage is high. The alloys may be hot-rolled up to 11 or 12 per cent. of nickel. The best material for rolling is that with 4 per cent., whilst 10 to 12 per cent. may be used for castings on account of the very low shrinkage. Cobalt has very nearly the same effect as nickel, and has no special advantages. Iron has a still greater effect in reducing shrinkage, and appears to have a favourable influence on the resistance to weather. The strength increases slowly up to 4 per cent. of iron and then slowly falls, whilst the ductility falls rapidly. The alloys do not appear to have special advantages, but may be useful up to 4 per cent. of iron.

Antimony alloys with aluminium in all proportions. Tensile strength and hardness are unaffected even up to 10 per cent., and these alloys may be hot-rolled, although from 8 per cent. onwards partial lamination occurs. The addition of 1 per cent. of antimony increases the ductility, after which point it falls. The alloys have thus no special technical value.

Silicon, in quantities up to 19 per cent., does not exert a very great influence on the corrodibility of aluminium, although very small quantities may do so. The strength and hardness increase regularly up to 12 per cent. of silicon and then remain constant. The ductility falls slowly. The alloys may be rolled without difficulty up to at least 20 per cent. As the specific gravity of such alloys is as low as that of aluminium, the addition of silicon is very advantageous, 5 to 7 per cent. being desirable for rolling, and 10 to 12 per cent. for casting.

Cadmium does not alloy with aluminium above 3 per cent.; its addition has no advantage whatever.

Tin has little effect in reducing shrinkage, and entirely prevents hot-rolling down to 200° C. Cold-rolling is successful. Up to 5 per cent. of tin the tensile strength is constant and then begins to increase slowly. The hardness is constant, whilst the ductility steadily falls.

Lead has no bad effect when present in about 0.5 per cent., and increases the ductility. Only small quantities can be alloyed with aluminium, and its addition presents no advantages. Bismuth is harmful, and also alloys only in small proportions.

Chromium may be added up to 5 or 6 per cent., beyond which the casting temperature becomes excessively high. Shrinkage is reduced, and the crystals become very coarse beyond 3 per cent. The alloys may be rolled at 500° C. up to 4 per cent., and give a greatly increased tensile strength but low ductility. The hardness increases to 1 per cent. and then falls.

Manganese at first increases shrinkage. The alloys may be hot-rolled more or less successfully up to 5 per cent., the tensile strength increasing throughout, and the ductility falling. From 1 to 2 per cent. may be used in the rolled alloy but without special advantage.

Tungsten dissolves more readily in aluminium than chromium or manganese. The shrinkage is scarcely affected. The tensile strength and hardness of the hot-rolled alloys increase a little at first, but

become constant at 1 per cent.; the ductility falling slowly. Molybdenum also alloys readily, but requires a high casting temperature. The alloy with 0.5 or 1 per cent. of molybdenum may be used when hot-rolled, but has no special advantages.

Vanadium alloys with difficulty. Alloys up to 4 per cent. roll quite well at 500° C., the tensile strength and hardness increasing up to 2 per cent. while the ductility falls slowly. Titanium gives alloys of very high melting point, so that an alloy with 5 per cent. of titanium must be cast at 1100°. Hot-rolling is possible up to 6 per cent. The strength rises rapidly up to 1 per cent., and then slowly, the ductility falling in a similar manner. Zirconium gives almost exactly the same result. Tantalum has little effect on strength, ductility or working properties.

Copper is the most useful of all the alloying metals, magnesium coming next. Zinc gives the highest tensile strength, but the alloys corrode readily. Silicon and nickel stand next in usefulness as additions to aluminium.—C. H. D.

Manganese Nitride.—An investigation of the magnetic substances formed by heating manganese in dry nitrogen or ammonia, by T. Ishiwara, * shows that three ferro-magnetic substances may be obtained between 600° and 1000° C. in nitrogen, namely Mn_5N_2 , a second nitride of undetermined composition, and a solid solution. The compound described by other investigators as Mn_7N_2 has not been confirmed. In ammonia, a third nitride, Mn_3N_2 , has also been obtained, this compound being only paramagnetic. The nitrides give characteristic thermomagnetic curves.—C. H. D.

Nickel-Tungsten Alloys.—According to R. Irmann † commercial cube nickel melted in a carbon crucible lined with magnesia does not dissolve tungsten at 1800° C. By using an electric furnace with a carbon electrode, however, a homogeneous 50 per cent. alloy may be prepared, and this may be melted with further quantities of nickel without difficulty. The quantity of each alloy made in the experiments was sufficient to allow of the casting of test-bars for tensile tests.

The thermal analysis is not very satisfactory, owing to the rapid rate of cooling. The arrests are stated to be so small as to be detected on the autographic curves only by the use of the microscope. From the very scanty data a freezing-point curve has been constructed, on which two maxima are indicated at 1480° and 1495° C., corresponding with the compositions $Ni_{10}W$ and Ni_6W respectively. It is thought improbable that the first of these can be a definite compound. There are three eutectic points, at 1426°, 1435°, and 1456° C. respectively. Solid solutions appear to be formed up to about 5 per cent. of tungsten. The

* *Scientific Reports of Tôhoku University*, 1916, vol. v. p. 33.

† *Metall und Erz*, 1916, vol. xii. p. 358.

relatively low melting point of all the alloys containing less than 50 per cent. of tungsten is remarkable. Richer alloys have not so far been prepared.

An examination of the action of sulphuric acid of different strengths on nickel at the temperature of the water-bath shows that the greatest attack is caused by 63 per cent. acid, and experiments with the alloys have therefore been made with this acid. The resistance of nickel to the acid is rapidly increased by addition of tungsten, until a maximum is reached at 18 per cent. of tungsten. From this point the resistance diminishes until the eutectic point at 25 per cent. is reached, beyond which it again increases. The resistant alloys scarcely lose their lustre after immersion in the hot acid for twelve hours, but specimens immersed in sea water or dilute nitric acid become covered with a blue layer of a lower tungsten oxide.

The electric resistance appears to increase regularly with increasing percentage of tungsten.

Both the tensile and compressive strengths at first diminish, reaching a minimum at about 25 per cent. in the former and 15 per cent. in the latter case. Beyond this point the strength rapidly rises. The alloy containing 18 per cent. of tungsten, which is forty times as resistant to sulphuric acid as nickel, may be rolled at 1270° C., and gives a fairly strong sheet.—C. H. D.

Nichrome Alloy Castings.—The development of the nickel-chromium alloy nichrome, well known throughout the electrical world as a resistor material, in the cast state in the form of boxes for heat treatment of steel, pyrometer protection tubes, crucibles, skimming ladles, &c., is described.* Heat-treatment boxes of nichrome possess the advantage over cast iron in that they retain their strength and shape at high temperatures and do not warp or bulge. They may be quenched in water whilst red hot. Owing to the greater durability of the alloy at high temperatures these boxes may be made half the thickness usually employed for cast iron, thus saving weight. These boxes may be had cast with walls $\frac{5}{16}$ to $\frac{1}{2}$ inch thick. The material loses very little of its strength at working temperatures of 950° to 980° C.

A pyrometer protection tube showed a life of 4000 hours. Tests have been made of nichrome crucibles holding up to 175 pounds metal. No especially careful handling or preliminary seasoning is required. Brass, copper and phosphor-copper have been successfully melted. Fifty heats of phosphor-copper were made in one crucible without visible signs of deterioration. Alloying of the nichrome with the melt does not take place. Tests on the crucibles are not quite completed. Furnace bottoms, supporting frames, &c., are other uses for the cast alloy. Nozzles for injector burners have been successfully tried.

In addition to its heat-resisting properties the alloy resists the cor-

* *Metallurgical and Chemical Engineering*, Aug. 1916, vol. xv (No. 3), p. 159.

rosion of acid mixtures, and has been used very successfully as a material for pickling-baskets. Nichrome can be readily machined and requires no special tools. It possesses a tensile strength about twice that of cast iron, and about the same hardness.—S. L. A.

Non-ferrous Alloys, Compositions of.—A very useful list of non-ferrous alloys, together with their chemical compositions, is published.* The list includes a very large number of trade alloys, and in addition to giving the usual limits of chemical composition frequently indicates the purpose to which the alloys are put. The number of alloys described runs into hundreds and the list should prove of considerable value to manufacturers.—D. H.

Sodium Amalgams, Resistance of.—Experiments with pure sodium amalgams have been made by R. C. Rodgers.† A eutectic point is found at 48.75° C. and 5.90 atomic per cent. of sodium. The experiments have been carried as far as 20 atomic per cent. The temperatures used ranged from -185° to +150° C., the amalgams being contained in glass tubes and surrounded by copper resistance thermometers. When the freezing points are plotted against the percentage change of resistance on freezing, a sharp bend in the curve is found at the eutectic temperature. When the percentage change of resistance is plotted against the atomic composition, however, a smooth curve is obtained.—C. H. D.

White Metal, Treatment and Preparation of.—An investigation of the treatment and preparation of white metal for bearings is described by G. F. Zimmer.‡ The effect of remeltings and of the conditions of casting on the resulting alloy has been studied, with special reference to the microstructure.

Remelting has very little effect on the chemical composition of the metal. A sample which had been six times re-melted showed the following analyses after the first and last re-casts:—

	After 1 Recast.	After 5 Recasts.
Tin	86.43	85.86
Antimony	8.76	8.58
Copper	4.51	5.33
Lead	0.04	0.02
Iron	0.07	0.08
Arsenic	0.05	0.04
Sulphur	0.01	0.02

The losses are mainly confined to the tin and antimony and are relatively slight, and have no noticeable effect on the microstructure. Further, these alloys had identical mechanical properties and melting points. The microstructure shows three main constituents. The

* *Metal Industry*, Aug. 18, vol. ix, No. 7, p. 195.

† *Physical Review*, 1916 (ii.), vol. viii, p. 259.

‡ *Metal Industry*, July 7, 1916, vol. ix, p. 4.

principal mass is a dark etching constituent consisting largely of tin, and in this are set two other light etching constituents, one needle-shaped containing most of the copper in combination with tin, and the other cubical, and consisting of approximately equal proportions of antimony and tin. The conditions of casting have a very marked effect on the microstructure. Two main factors of this operation were studied—the temperature of casting, and the rate of cooling during solidification. Low temperature casting from 400°C. , about 30°C. above the melting point, followed by rapid cooling during the solidification produced a very small structure containing small thin needles rich in copper and small cubes of the antimony constituent. The fracture under these conditions is dull grey and finely granular. The same casting temperature followed by slow cooling produced a very much larger structure, the cubes being very much larger in size, while at the same time the needles became thickened and tended to become star-shaped. The fracture under these conditions is coarsely crystalline. A high casting temperature (700°C.) combined with a quick rate of cooling produces a relatively small structure, but the needles tend to arrange themselves in chains of considerable length. The fracture is finely crystalline. High casting temperature with a slow rate of cooling results in the formation of large cubes and large chain-like needles and gives a coarse crystalline fracture.

The microstructures show that rapid cooling has a much greater effect on the quality of the finished casting than the casting temperature, though the best results are obtained by using a low casting temperature with a rapid rate of cooling.

The quickly cooled castings also show a greater hardness than those slowly cooled, and the appearance of the upper surface of the casting also depends on the rate of cooling, quickly cooled castings showing a funnel-shaped shrinkage, whilst slowly cooled castings present a level surface.

The addition of small quantities of magnesium or aluminium, to prevent oxidation, causes a slight increase in the hardness of the alloy, but the effect of these additions in other directions was not determined. In view of the slight effect of re-melting, however, such additions do not appear necessary.

The paper is illustrated by six photomicrographs.—D. H.

III.—METALLOGRAPHY.

Electrolytic Copper, Microstructure of.—The structure of electrolytic copper under varying conditions of deposition and annealing is the subject of a paper by H. S. Rawdon.* The special feature studied

* *Transactions of the American Institute of Metals*, 1917.

was the occurrence of twinned crystals, and the conditions under which these could be formed. It was observed that with low current density the crystals are large and well formed except on the surface of initial deposit where a thin layer of very fine crystals is always found. With higher current density the crystals are long and grow at right angles to the surface of deposit, giving a columnar appearance under the microscope. With still higher current density the structure is considerably broken up, and twinned crystals are common. It is also observed that the twinned crystals are, in general, at right angles to the direction of crystal growth, which fact suggests that they are formed during the process of deposition.

The author suggests that these twinned crystals are the direct result of mechanical strain during the growth of the crystals. The mutual side thrust of the growing crystals is enough, in many cases, to cause the layer which is being deposited on any one crystal to assume the position of twinning with respect to the immediately preceding layer.

Deposits made under conditions which give a columnar or broken up structure should exhibit some of the properties of cold-worked material, if the quality of the microstructure is to be attributed to internal stresses during formation, and hardness and tensile tests confirm this view. It is also shown that whereas annealing has little or no effect on deposits made under a low current density, it has a very pronounced effect on the finer deposits, causing them to recrystallize with very considerable twinning, in exactly the same manner as cold-worked copper. There is at the same time considerable crystal growth.

The paper is illustrated by a series of photomicrographs.—D. H.

Etching, Methods and Results of.—A general review of the subject of metallographic etching, with some new observations, is given by J. Czochralski.* The boundaries of crystal grains have properties similar to those of cold-worked metal. Thus metals which are rendered more soluble by cold work, such as iron, show channels between the grains on etching, whilst those which are rendered less soluble, such as copper and aluminium, show ridges after etching. Many photographs of etching figures are given.

After severe cold work, the varied reflex of neighbouring crystal grains disappears and is replaced by a uniform granulation, but the grain boundaries still remain visible. The depth to which the cold work has penetrated in a rolled metal may be shown by annealing and etching; the growth of new crystals does not extend through the metal, but only to the depth of the strained layer. Twinning is also produced by severe cold work, and increases on subsequent annealing. Fine, parallel deformation lines, probably twins, are readily produced by straining copper, gold, lead, and their solid solutions, whilst α -iron,

* *Stahl und Eisen*, 1915, vol. xxv. pp. 1073, 1129.

aluminium, and β -brass do not show this effect. The strained portions are not regarded as amorphous, but as consisting of molecules which are forcibly displaced by shear (Lehmann's "forced homotropy"). This condition is regarded as being essentially different from an amorphous state.

Velveteen polishing cloths and liquid commercial polishing mixtures are recommended. Polish attack is useful in many cases. The following notes on etching reagents may be given :

Concentrated hydrochloric acid is useful for lead, tin, antimony, bismuth and their alloys. It is often advisable to allow a drop of the acid to evaporate on the surface of an alloy. A dilute solution in alcohol is used for steel, aluminium, magnesium, zinc and some of their alloys. With pure zinc, which is scarcely attacked, the action may be brought about by contact with copper. A mixture of 10 to 20 c.c. of hydrofluoric acid with 100 c.c. of alcohol etches aluminium; this reagent may be followed with advantage by concentrated hydrochloric acid. Concentrated nitric acid may be used for copper, silver, cadmium and some of their alloys, and alcoholic nitric acid for steel, cast iron and lead. Sulphuric acid, freshly diluted with an equal volume of water and used warm, etches the dendritic alloys of copper and tin well and may also be used for $\alpha\beta$ -brasses. A 10 per cent. solution of chromic acid etches copper, zinc, cadmium and many alloys of these metals, whilst a highly concentrated solution of chromic acid is suitable for developing the internal crystalline structure of zinc.

Ammonia, the most useful reagent for copper and brasses, is best applied by rubbing lightly with cotton wool. A 10 per cent. solution of ammonium persulphate is also recommended.—C. H. D.

IV.—INDUSTRIAL APPLICATIONS.

Aluminium Castings and Forgings.—P. E. McKinney* gives an account of the production of aluminium alloy castings and forgings. The particular alloys studied are those containing small amounts of manganese and copper, which have been adopted as a result of data published in the Ninth Report of the Alloys Research Committee. The use of manganese with or without copper is recommended because it strengthens and hardens the alloy without impairing its ductility. The machining properties also are excellent, and it is possible to make quite intricate castings with comparative ease.

The most satisfactory method of making these alloys is first to make an alloy rich in manganese, having a definite composition and a relatively low melting point. At the same time particular care must be taken throughout to exclude carbon, silicon and iron, and carbonless

* *Transactions of the American Institute of Metals*, 1917.

manganese obtained by the thermit process should be used. This may be added to molten copper in small pieces to give an alloy containing 40 per cent. of manganese, this alloy being then remelted with an equal quantity of aluminium, or an alloy containing 20 per cent. of manganese and 80 per cent. of aluminium may be made direct by first melting the aluminium, heating to a bright red and then adding the manganese in very small pieces until all is dissolved.

It is recommended that the hardening alloy be first melted in a clay pot, the aluminium being afterwards added as rapidly as it will melt. Care must be taken to avoid overheating. A flux of 60 per cent. potassium chloride and 40 per cent. cryolite is used to prevent the entrance of silica, and just before pouring a small amount of zinc chloride is added, which is said to reduce oxides and dross.

Tests on sand castings of an alloy containing 1.5 per cent. manganese and 2.0 per cent. copper gave the following results: tensile strength 18,000 lb. per sq. in. to 24,000 lb. per sq. in., elongation on 2 in. 8 per cent. to 15 per cent. The elastic ratio is about 60 per cent. of the ultimate strength.

In preparing ingots for forging the same precautions should be observed in melting. The ingot moulds are heated to about 260° C., and the metal is poured quickly to avoid cold shuts.

For making drop forgings preliminary forging is very desirable. The ingot is cut to the desired lengths and forged hot, after which it can be finished in the dies. The properties of the forgings can be controlled by varying the finishing temperature.

A soft alloy containing 1 per cent. manganese and 2 per cent. copper had a tensile strength varying between 21,000 lb. per sq. in. in the hot finished state and 27,750 lb. in the cold finished state, the respective elongations being 12 per cent. and 27 per cent. A hard alloy containing 2 per cent. manganese and 3 per cent. copper had a tensile strength varying between 27,000 lb. and 34,000 lb. per sq. in. in the hot and cold finished conditions respectively, the corresponding elongations varying between 22 per cent. and 4 per cent.

The forged metal is said to resist sea-water corrosion better than the cast alloy.—D. H.

Aluminium Dust.—The uses of aluminium dust are described.* In the mining industry it is used for precipitating the precious metals from cyanide solution. In the production of carbon-free metals it is used as a powerful metallic reducing agent and also in the thermit process of welding. It is also used as a "bronze powder" in the preparation of aluminium paint. At the present time it is largely used in the manufacture of explosives, such as "ammonal," a mixture of aluminium dust and ammonium nitrate, which is insensitive and very stable.

* *Mechanical World*, June 1916, vol. ix. p. 29.

Aluminium dust is made in several ways. One method involves the production of foil, which is comminuted in two series of special stamp mills, the product being separated by bolting and winnowing, and finally polished in a special device.

Another method is to force gas and air into molten metal while solidifying, accompanied by vigorous stirring. The granules formed are powdered in stamp mills or ball mills.

Stearine or some other wax must be used in all methods of manufacture, in order to prevent welding together of the fine particles during crushing.—F. J.

Aluminium—Welding of Sheet.—Notice is made of a special blow-pipe developed in America for the joining of aluminium, particularly in sheet form, by oxy-acetylene welding.* The mode of operation recommended is described, with illustrations, and a number of precautions to be observed in the use of the flux, &c., in order to obtain a sound and reliable joint, are given.—S. L. A.

Brass and Bronze Castings.—A comprehensive list of the various bronzes and brasses used for making castings, together with their properties and uses is given by W. M. Corse and G. F. Gomstock.† The list is compiled from a number of sources and gives, when they are available, the chemical analysis of the alloy, the mechanical tests, including yield point, ultimate stress, elongation, reduction of area, Brinell hardness, scleroscope hardness, and elastic limit in compression. The various uses to which the castings are put are also indicated. The list should prove of considerable use to manufacturers.—D. H.

Bronze Parts in Movable Bridges.—In an article compiled from the report of a Committee submitted to the American Railway Engineering Association, C. E. Stone‡ discusses the several uses of bronze in the construction of movable bridges and points out the composition and treatment necessary to meet the various requirements.

For many purposes the uses to which the bronze is put are not severe tests of a bearing metal, and conditions other than that of friction have to be taken into consideration. For some uses the resistance to wear may be the deciding factor, but very frequently a large amount of compression strength and resistance to sustained pressure without flowing is required. For other purposes resistance to tension is most important, while for use with rotating parts the hardness must be regulated lest these suffer from abrasion. An interesting condition mentioned in the report is that fineness of microstructure is important. Not only are high physical properties associated with a fine microstructure, but wearing, which consists of the dis-

* *Metallurgical and Chemical Engineering*, May 1916, vol. xiv (No. 9), pp. 548-9.

† *Metal Industry*, Oct. 13, 1916, vol. ix, (15), p. 434.

‡ *Ibid.*, Aug. 4, 1916, vol. ix, No. 5, p. 137.

lodging of the hard particles from the soft matrix, is much more likely to be less severe if these particles are small.

For centre-bearing discs or draw-spans, in which the pressures may be from 3000 to 3500 lb. per sq. in., and where there is no fast movement, a hard bronze is necessary. In this case the moving parts are generally of hardened steel, and the number of revolutions during the lifetime of a bridge is small, so that the hardness of the bronze need not be limited by fear of abrasion. The compression strength, however must be high, and a bronze containing 20 per cent. of tin and 0.8 to 1.2 per cent. of phosphorus is frequently used. This is an extremely brittle material which may show an elastic limit of 30,000 to 40,000 lb. in compression.

In trunnion bearings carrying medium or low carbon steel trunnions at low speeds the pressures calculated on the projected area of the trunnion vary usually from 1500 to 2000 lb. per sq. in. The actual unit pressure at the surface of contact may, however, and probably always is, considerably greater than this estimate. Further, during periods of rest, the oil film may be squeezed out and on starting up a certain amount of gripping of the trunnion may occur, with a considerable increase in the friction. A hard bronze is therefore desirable. The chance of shock, together with the possibility of unevenness of the support of the bushing, make brittleness undesirable, and although bronzes containing 20 per cent. of tin have been used, they are considered rather brittle. Standard lead-bronze (tin 10 per cent., lead 10 per cent.) has also been used for trunnion bearings, but a medium bronze containing about 14 per cent. of tin is preferred.

A soft lead-bronze is required for soft bearings which work under light loads at high speeds. Lubrication is generally continuous and friction from the running dry of the bearing is not likely to occur. The tin content should be low, as it is then easier to secure uniformity of distribution of the lead. A lead-phosphor-bronze containing 10 per cent. lead and 10 per cent. tin is recommended.

For gears and worms resistance to tensional stresses and to wear are important. The hardness must be such that the metal will not flow, while the pinion or gear engaged will not become abraded. It must not be sufficient to render the alloy brittle under shock. A lead-bronze is too soft and uncertain in tension. A gun-metal containing 10 per cent. of tin and 2 per cent. of zinc is recommended. Phosphorus is said to be unnecessary.—D. H.

Cartridge Brass Manufacture.—A description of the process of manufacture of cartridge brass is given by C. R. Barten.*

The maximum allowable percentage of impurity in the zinc used should be lead 0.3 per cent., iron 0.04 per cent., cadmium 0.20 per cent.; total not exceeding 0.25 per cent. [*Note by Abstractor:* If this is not a misprint in the original article, it can only be interpreted

* *American Machinist*, June 1916, vol. xliv. p. 837.

to mean that no *combination* of impurities may total over 0.25 per cent.] In the copper used the total impurities should not exceed 0.03 per cent.

Only scrap from the blanking, overhauling and shearing machines should be added to the mixture for melting and should not exceed 65 per cent. of the charge.

Specifications for chemical analysis allow a variation from 67 to 71 per cent. copper and from 0.2 to 0.4 per cent. total impurities. The combined percentages of arsenic, antimony, phosphorus and cadmium must not exceed 0.08 per cent.

The minimum breaking stress specified varies from 40,000 lb. per sq. in. to 44,000 lb. per sq. in., the maximum varying between 48,000 and 50,000 lb. per sq. in. The minimum elongation required varies from 50 to 62 per cent., no standardized test-piece being specified. The specimens are cut from annealed blanks. A cupping test is also specified. Other details of specification, e.g. variations in dimensions, flaws and defects, methods of inspection, &c., are described.

The plant for the manufacture of cartridge brass is described in detail. The casting shop and furnaces are described, the square type pit-furnace being preferred. Coke fuel is preferred and a depth of fire of 12 in. beneath the bottom of the crucible advocated. A natural draught system is regarded as more satisfactory than one of forced draught.

Using a 21-inch square furnace, the largest number of heats claimed per 24 hours is 21, but owing to the difficulty of getting men to work at such a strenuous rate and to the reduced life of crucible this number is usually dropped to 15 in cold, and 10 or 12 in warm weather.

Other types of furnace, such as the Schwarz, do not find favour because of the necessity involved of pouring the metal a second time.

The fuel consumption is estimated at from 0.4 to 0.6 lb. of coke and coal (mixed) per pound of metal melted, employing 18-inch round and 21-inch square furnaces.

The moulds, which are of grey iron, are described and illustrated. They should be planed at the joint to reduce leakage and minimize stress when the bands are tightened.

A special strainer for keeping back dross is described. The life of a mould should average 2000 to 2500 heats. The special tools employed by the caster, e.g. various tongs, &c., are described and illustrated.

The composition and treatment of crucibles are described and the conditions tending to shorten their life indicated. A crucible holding 200 to 300 lb. of metal is found to be the best size.

The use of fluxes is dealt with, common salt being recommended.

As a deoxidizer 1 oz. of 15 per cent. phosphor-copper is recommended per 100 lb. of metal.

The metal-storage room, the shearing of bars and the weighing of metal and scrap are described.

The practical details of the melting and pouring operations are described, also the preparation of the moulds.

The melting loss, which is usually from 3 to 5 per cent. gross and

from 1 to 3 per cent. net (after allowance for recovery of metal from ashes), represents a greater amount of money than the profit in manufacture and should receive careful attention.

Lists of equipment and material used are given and also a table showing the distribution of metal between weighed charge and sheared bars.—F. J.

Cartridge Brass, Rolling.—The rolling into finished bars suitable for blanking, of the rough sheared strips furnished by the casting shop, is described by C. R. Barton.* The operations involved are breaking down in rolls, straightening in rolls, scraping in overhauling machines, inspecting, running down in rolls, annealing, pickling and drying.

The breaking-down rolls (20 inches diam. by 30 inches face) are of cast steel and are driven through a gear train by a 200-h.p. motor run at 14 revs. per minute or about 73 ft. per minute. The finishing rolls are chilled cast iron and have a speed of 18 revs. or about 94 ft. per minute.

A reversing switch for use when bars stick in the rolls and a positive brake for quick stopping in case of accident are desirable.

A number of technical phrases are defined, e.g. "sticking," "biting-up," "pinch," "breaking-down," &c.

Other details of the rolls and rolling practice are described. Oil prevents biting-up and a dusting of charcoal should be applied.

Bars are sometimes curved or bent, of uneven gauge or rough finish. These troubles may be attributed to various causes which are enumerated. The following fundamental principles in considering the action of rolls on brass bars of uniform thickness are: (1) that the rolls spring apart in proportion to the total pressure exerted on the metal; (2) that the amount the metal flows or the bar elongates at any point depends upon the pressure which the rolls exert and the hardness of the metal; that the metal may vary in hardness owing to inequalities of chemical composition, annealing or mechanical treatment; that, theoretically, the peripheral velocities of both upper and lower rolls should be the same.

Bars, however, are not always of uniform thickness and variations in thickness may occur in the same bar. Such variations from uniformity as may occur are handled by a skilful roller. A back-plate is fixed in position near the rolls so as to determine the curve in the sticking end of the bar.

This plate is described and illustrated, as also are the straightening rolls and overhauling machine; the latter is a scraping machine adapted for removing surface metal from the bars to the extent of 0.02 to 0.04 inch in thickness.

Any defects too deep for removal in this machine are removed with chisels when being inspected. Each machine overhauls 10 to 14 bars per hour. The bars are then "run-down" in 3 or 4 passes to a suitable thickness for finishing, annealed in order to equalize the degree of hardness and obviate sorting, and then pickled.

* *American Machinist*, Sept. 1916, vol. xlv. p. 331.

A scheme of reduction for one grade of cartridge brass is cited and a list of grades of hardness of commercial methods.

Proper annealing depends upon the temperature reached, therefore the temperature of the furnace must be even. The bars must increase in temperature at the same rate and there should be a reliable method for determining temperatures. For annealing 67 : 33 brass to secure a minimum tensile strength of 43,500 lb. per sq. in. and a minimum elongation of 57 per cent. on 4 inches, a temperature of about 675° C. is sufficient.

Special methods of coupling and loading the annealing pans are employed.

Strips up to 18 ft. long are handled, longer lengths being coiled. The pickling tanks and appliances are described.

With the equipment described in the article it is claimed that 1,500,000 lb. of cartridge metal can be finished per month.—F. J.

Cartridge Case, Manufacture of.—A description is given by R. Mawson * of the successive operations performed in the manufacture of the 18-lb. cartridge case. Illustrations are given of the various machines set up for the operations. The special tools such as punches and dies, gauges, &c., are also included.

Rates of production, times and temperatures of annealing, pickling solutions used are given in detail.

The operations performed in the manufacture of the case are :

- | | |
|--|------------------------------------|
| 1. Blank 16-375" diam. × 0-380" thick. | 17. Annealing and Washing. |
| 2. Mark for identification. | 18. Sixth Draw. |
| 3. Cupping. | 19. Second Trim. |
| 4. Annealing and Pickling. | 20. Washing. |
| 5. First Draw. | 21. First and Second Heading. |
| 6. Annealing and Pickling. | 22. Flash Annealing. |
| 7. Second Draw. | 23. First Taper. |
| 8. First Indent. | 24. Second Taper. |
| 9. Annealing and Pickling. | 25. Machining Head. |
| 10. Third Draw. | 26. First Inspection. |
| 11. Annealing and Pickling. | 27. Stamping and Washing. |
| 12. Fourth Draw. | 28. Hand-tap for Primer. |
| 13. Second Indent. | 29. Final Inspection. |
| 14. Annealing and Pickling. | 30. Government Inspection. |
| 15. Fifth Draw. | 31. Stamping, Boxing and Shipping. |
| 16. First Trim. | |

The composition of the metal is :—

	Per Cent.
Copper	67 to 72
Zinc	33 to 28
Lead	under 0-10
Iron	„ 0-10

The physical properties are :—

Ultimate Tensile Strength	48,000 lb. per sq. inch.
Elastic Limit	17,000 „ „
Elongation	71 per cent.

* *American Machinist*, September 1916, xlv. p. 319

Casehardening Bronze for Dies.—The hardest bronzes are least affected by wear when used as dies, but they are too hard to allow of chasing and sinking fine intricate designs.*

A soft bronze which will allow of chasing and sinking, may be face-hardened in order to increase its wearing properties. This is effected by coating the surface with pure tin, subsequently heating at a low red heat in order to form a hard surface alloy. The surface is first treated with hot potash to remove grease and then pickled in 20 per cent. sulphuric acid. Chloride of zinc solution is then put on, after brushing, to act as a flux. Pure tin is then melted on the surface by the aid of a soldering iron or preferably a torch or blow-pipe.

As little tin as possible is put on so as not to fill up fine detail.

After washing in water and if satisfactorily covered, the die is heated to a red heat, preferably in a muffle, after coating the surface with a strong solution of boracic acid to prevent oxidation. Owing to the brittleness of the die at a red-heat, it should be introduced into and withdrawn from the muffle on an iron plate. The heating period is from 10 to 15 minutes. After cooling, the die is washed in warm water and pickled if necessary. The surface should be quite hard and difficult to file.

Such hardened dies are used for stamping leather, soft metals, paper, &c.

The bronze recommended for the purpose consists of copper 88, tin 8, zinc 2, and lead 2 parts.—F. J.

Copper Wire Splices, Mechanical Strength of.—A series of comparative tests to determine the relative strength of splices with different grades of copper and the ability of conductors to stand injury under service conditions are described by E. R. Shepard.†

The Bureau of Standards, in attempting to prescribe suitable sags in line conductors which would at once meet the requirements for proper unit stresses under the maximum assumed loading conditions and also provide reasonable assurance against their blowing together in the wind, encountered a difficulty where the smaller sizes of wire are commonly used in moderately long spans.

Transmission companies objected to the proposal to exclude the smaller size of soft-drawn wire from long spans and hazardous locations on the ground that medium-drawn copper wire is difficult to handle, does not lend itself well to the making of splices and caps and is more easily broken by rough handling and vibrations on the line.

Tests were made on the mechanical strength of "Western Union" and sleeve splices and an investigation was made to determine the relative hardness of the surface and interior of different grades of copper.

It is pointed out that there is a margin of only 50 or 60° C. between the temperatures at which solder will flow and at which hard-drawn

* *Mechanical World*, Sept. 1916, vol. ix. p. 140.

† *Ibid.*, August 1916, vol. lviii. p. 386.

or medium wire will anneal. Pouring solder from a ladle is less likely to overheat the wire than using a blow torch for making up the soldered splices.

Experiments made on a No. 6 wire both by dissolving off the outer "skin" in acid and by turning it off in the lathe showed that the inner core had a higher tensile strength than that of the original section.

Vibration tests were made in a specially designed machine, in which a piece of wire is held rigidly at one point. The other end of the wire runs over a pulley 2 ft. from the fixed end and a 50 lb. weight is suspended from it. A motor is belted to a crosshead which vibrates the wire at a centre point about 600 double vibrations per minute, giving an amplitude of 2 inches.

The results of all the tests are shown in the following tables.

It is claimed that, whilst hard and medium wire may be in some respects objectionable for general line use, the experiments show that there are no serious limitations to its use.

TABLE I.—*Tests on Splices.*

Description of Wire.	Type of Splice.			
	Contin- uous.	Western Union Splice Not Soldered.	Western Union Splice Soldered.	Sleeve Splice.
		lb.	lb.	lb.
No. 6 W.P. Copper, Medium	1135	449	751* 1077	1035
No. 4 " "	1632		1428 1465	1540
No. 6 Bare Copper "	1106	578	1006	1430
No. 6 " Hard	1326	782	1222	Wires sandpapered. 1168 and 1217 Wires sandpapered.

TABLE II.—*Tests on Treated Wires.*

Description of Wire.	Treatment.	Breaking Stress. Lb. per Sq. In.
No. 4 Soft Copper.	Diam. 0.203"	35,150
" "	Diam. reduced to 0.155" by turning	36,200
No. 6 Hard Copper.	Full Section	62,000
" "	Diam. reduced from 0.165" to 0.143" in acid	63,200
" "	Diam. reduced by nicking	64,000
No. 00 Trolley Wire. Hard.	Full Section 0.364" diam.	51,200
" "	Diam. reduced to 0.327" by acid	52,200
" "	Diam. reduced to 0.319" by acid	52,400
" "	Diam. reduced to 0.248" by turning	52,800

* Soldered at high temperature.

Fusible Plugs.—The fusible plug is made of brass, a conical or concave depression penetrating to about $\frac{3}{8}$ inch or $\frac{1}{2}$ inch of its entire thickness; a $\frac{1}{4}$ -inch hole is then drilled right through it.* This brass plug, measuring $1\frac{1}{4}$ inch to $1\frac{1}{2}$ inch in diameter, is filled with a soft metal melting at not less than 313° C. (650° F.). The plug is applied between the first and second rows of crown bolts or radial stays at the front end of the firebox near the back flue sheet, at which locality low water would be first in evidence, as the crown sheet at this point is about 3 inches higher than any other part of the firebox. The function of the fusible plug is to indicate low water. When unprotected by water, the temperature at this point rapidly increases, causing the fusible metal to melt and allow steam and water to enter the firebox and extinguish the fire, thereby putting the locomotive temporarily out of action without further damage. Rupture of the crown sheet and possibly a boiler explosion are averted.

If allowed to remain over 30 days, a scale forms over the fusible metal and mud accumulates; thus the temperature increases and the fusible metal melts even though the water has not gone too low. When a plug does perform its proper function the engine-driver may conceal the fact in order to protect himself, or the inclination of the track may affect the level of the water so as to produce fusion of the plug when low water does not really exist.

Positive disadvantages are as follows:—

1. In the position where plugs are placed they are subjected to the intense heat of the fire which burns them out frequently.

2. The distance between the water end and the fire end of the plug is so great that the high temperatures at the fire end may melt the fusible metal even when the water is not low.

3. Owing to variation in temperature between plug and surrounding metal of the crown sheet, it is very difficult to maintain a tight joint. Replacement of the plug by a new one is recommended once a week, although this procedure involves enlargement of the hole in the crown sheet and therefore increase in diameter of plug, necessitating application of a patch or bushing of the hole, which in time becomes more troublesome than a leaky plug.

4. The frequent removal of plugs involves lowering the water each time. If cold water is forced in to raise the level, the flues and firebox sheets are damaged.—F. J.

“Manganese Bronze,” Stresses produced by Burning-in.—The investigation of the stresses set up in castings of tin-brass or “manganese-bronze” as a result of the burning-in of defective areas, is the subject of a paper by Paul D. Merica and C. P. Karr.† As a result of the extreme local heating and the consequent unequal con-

* *Mechanical World*, Oct. 1916, vol. ix, p. 106.

† *Transactions of the American Institute of Metals*, 1917.

tractions during cooling, very severe local stresses are set up in castings which have been repaired in this way, and these stresses are sufficient to cause the ultimate failure of the casting.

Experimental castings were made in the form of a double-bar frame, the larger cross-bar having a cross-section area nine times as great as the smaller cross-bar. A portion of the smaller bar was removed by sawing, and was replaced by burning-in with the same material. The pouring gate was removed and gauge marks made on the bar on either side of the burnt-in portion. Readings were then taken with a strain-gauge before and after cutting through the bar outside the gauge marks. The elastic modulus of the material being known, and the contraction over the gauge length, which was 8 inches, being measured, it was possible to calculate directly the stress in the bar.

The material used was a tin-brass or "manganese-bronze" containing 58.5 per cent. copper, 39.1 per cent. zinc, 1.0 per cent. tin, 1.4 per cent. iron and no manganese.

Measurements showed that considerable stresses, of from 8000 to 10,000 lb. per sq. in., were set up in the bars, and that this was practically the value of the elastic limit for this material. The interesting fact was also established that the welded area was stronger than the mass of the casting, and microscopic examination showed that this was due to the refined structure produced by the more rapid cooling.

The conclusions arrived at are that :

1. Welding-in or burning-in of constrained parts of castings of tin-brass produces in general local initial tensional stresses within and near the burnt-in zone, of a value equal to the true elastic limit of the material, unless the shape of the casting is such that extensive distortion may occur.

2. Such castings should, therefore, be either preheated for welding, so that all parts of the casting cool down together from a dull red heat, or the casting should be subsequently annealed. Experience indicates that a low temperature anneal is sufficient for this purpose, e.g. from 400° C. to 500° C. for from one to two hours. Either of these precautions should eliminate these local stresses otherwise resulting from the burning-in and should produce castings free from danger of subsequent cracking.—D. H.

Non-ferrous Scrap Metal.—The phenomenal rise in the price of scrap metals and alloys has emphasized the importance of reclaiming all discarded or waste material.* A striking instance of the systematic recovery of discarded metal is given in the case of railroad journal bearings which, at the brass foundry of the Pennsylvania railroad, form 75 per cent. of the melting charges in the manufacture of new bearings.

Broken valves, spindles, nipples, &c., form another source of

* *The Foundry*, June 1916, vol. xliv.

scrap brass, whilst 75,000 lb. of turnings in phosphor and plastic bronze are recovered per month by means of the magnetic separator.

In the manufacture of soft metal packings for piston and valve stems, the melting charge contains 50 per cent. of scrap metal, the charges being calculated from careful analyses of the remelted scrap.

The foundry floor sweepings provide 7000 lb. of clean brass per month. The sweepings are crushed and washed and passed through a magnetic separator.

Discarded crucibles are allowed to accumulate and then disposed of to smelters.

The remelting of copper wire after burning off the insulating material, of lead from the car seals, of the lead, zinc, and mud from the batteries, and of lead from obsolete driving wheel centres of locomotives form other sources of recovery of non-ferrous metals.—F. J.

Wire-Drawing. Power Needed for.—A formula is given * for determining the horse-power required to draw wire, as follows :—

$$\text{H.P.} = T (A-a) S \frac{F}{33000}$$

where T = Tensile strength of material in lb. per square inch before drawing.

S = Speed of drawing in feet per minute.

A = Cross-sectional area of wire before drawing in square inches.

a = Cross-sectional area of wire after drawing in square inches.

F = Factor selected from a curve in which percentage reductions of area are plotted as abscissae and factors as ordinates.

F. J.

V.—CORROSION.

Corrosion and its Prevention.—The serious corrosion which takes place on those fittings which have to conduct sea-water to various points in the modern steamship has received the attention of F. J. Rogers,† who after careful observation of salt-water pipes, is convinced that the excessive pitting which occurs is due to a gas or combination of gases and that wherever a zinc plate or ring has been placed near to fittings to prevent galvanic action, severe pitting occurs at the top part of the inner surface of pipes as they are placed in the ship. The length of service is very short compared with that of pipes which have been free from the influence of zinc.

Cast-zinc rings when fitted into the apertures of supply and discharge pipes below the water-line have only acted as a part protection, adjacent portions of metal being rendered electro-negative, but portions at a greater distance being rendered more electro-positive, thus giving rise to voltaic action between these extremities.

* *Mechanical World*, vol. lx. p. 165.

† *Ibid.*, Oct. 1916, vol. lx. p. 176.

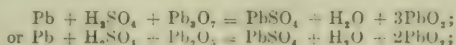
In the electro-chemical action between sea-water and metals hydrogen gas is evolved. Chlorine is also evolved and combines with the hydrogen to form hydrochloric acid—a powerful solvent. The free gases rise and pass through the pipes when the valves are open and when closed escape to the surface water along the outer skin of the hull. Eventually gases find their way into the boilers through the feed-pumps, travelling along through the tubes of the condensers with the circulating water, becoming trapped in the ferrules, forced into the condenser, carried down with the condensed steam and dissolved into the feed-water, which soon becomes highly charged with them, metals in the circuit upon which these gases can act being readily corroded.

The recommendation is made that, in cases where the practice of using zinc rings is continued, gas chambers should be fitted on the top parts of connecting pipes at, or as near as possible to the sea-valve, in order to trap gases so soon as they are evolved, small pipes leading them from the tops of the chambers to and through the hull above the water line.—F. J.

ELECTRO-CHEMISTRY

Flames, Validity of Faraday's Law for.—In the course of experiments made to determine the validity of Faraday's law for flame electrolytes, B. Thieme * has observed that the quantity of copper deposited when an electric current is passed through a flame sprayed with a solution of copper sulphate is in accordance with the law.—C. H. D.

Lead Accumulator.—The theory of the lead accumulator, still imperfect, has been further discussed by C. Féry, † whose experiments show that the usual sulphate explanation is untenable, the quantity of acid fixed during the discharge being just one-half of that to be expected from the older theory. The discharge is probably represented by one of the two equations :



the actual weight of peroxide formed lying between the two.

The electrical resistance of lead oxides diminishes with increasing proportion of oxygen, being very small for the peroxide.—C. H. D.

* *Berichte der deutschen physikalischen Gesellschaft*, 1916, vol. xviii. p. 221.

† *Journal de Physique*, 1916 (v.), vol. vi. p. 21.

METHODS OF ANALYSIS, TESTING AND PYROMETRY.

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I.—METHODS OF ANALYSIS.

Aluminium, Estimation as Oxide.—The conditions of this process have been investigated by W. Blum.* The quantity of ammonia added in excess during precipitation is known to be of importance, and indicators have been used for the purpose, but no exact limits have been drawn. It is now found, by using a hydrogen electrode, that the precipitation of alumina is complete when the hydrogen ion concentration is between $10^{-6.5}$ and $10^{-7.5}$, these points being approximately defined by the colour change of methyl red or rosolic acid, the former giving the better results, provided that enough ammonium chloride is present to coagulate the precipitate. It is recommended that at least 5 grms. of ammonium chloride should be present in 200 c.c. of solution. Dilute ammonia is then added to the nearly boiling solution until it is just alkaline to methyl red. After boiling for two minutes, the liquid is filtered rapidly. The addition of some filter-paper pulp facilitates both filtration and ignition. Ferric iron, if present, is completely precipitated with the alumina. The method is not suitable for separation from manganese or zinc. The alumina is washed thoroughly with a hot 2 per cent. solution of ammonium chloride or nitrate, and ignited over the blowpipe in a platinum crucible for five minutes after all carbon is burnt off. The ignited alumina is very hygroscopic.

—C. H. D.

Aluminium and Beryllium, Estimation of.—Aluminium is completely precipitated as the hydrated chloride, according to H. D. Minnig,†

* *Journal of the American Chemical Society*, 1916, vol. xxxviii. p. 1282.

† *American Journal of Science*, 1915 (iv.), vol. xl. p. 482.

when its concentrated solution is mixed with a solution of 1 part of acetyl chloride in 4 parts of acetone, iron remaining in solution. The aluminium is then converted into oxide and weighed. The acetyl chloride must be free from phosphorus compounds, and is best prepared by saturating acetic anhydride with hydrogen chloride and distilling at 100° C. in a current of the same gas. Beryllium remains in solution unless its quantity exceeds one-third of the aluminium, in which case it is liable to be carried down with the precipitate.—C. H. D.

Arsenic, Antimony and Tin, Separation of.—An improved method of separating these metals is proposed by F. L. Hahn.* The mixture of sulphur and sulphides obtained by acidifying the ammonium sulphide solution is extracted with a cold dilute (5 per cent.) solution of sodium sulphide, which extracts the metallic sulphides and leaves insoluble sulphur. The filtrate is made alkaline, using two volumes of a 10 per cent. solution of sodium hydroxide for each volume of the sodium sulphide. Hydrogen peroxide is added, and the solution heated to boiling. If antimony is present, it is precipitated in glistening crystals of the compound $\text{Na}_2\text{H}_2\text{Sb}_2\text{O}_7$, which cling to the glass where rubbed. A quarter of the volume of alcohol is added, and the precipitate is collected. Alcohol is expelled from the filtrate by boiling, and ammonium nitrate is then added. After boiling off ammonia, the precipitation of stannic oxide is complete. Arsenic is precipitated from the filtrate as ammonium magnesium arsenate. One mgrm. of arsenic or antimony and 2 mgrms. of tin may be detected in 1 gm. of copper or lead.

Another qualitative method of separating these metals is proposed by C. Pertusi.† The mixed sulphides are suspended in water and mixed with powdered magnesium, the mixture being filtered as soon as the yellow colour changes to brown. The residue is dissolved in hydrochloric acid and warmed; the presence of tin is indicated by a grey precipitate on the addition of mercuric chloride. Another portion of the mixed sulphides is shaken with magnesium powder and methyl alcohol, warmed, and filtered. On acidifying the filtrate, a bright yellow precipitate indicates arsenic. Another portion of the sulphide precipitate is dissolved in concentrated hydrochloric acid and mixed with a drop of 1 per cent. mercuric chloride solution and an excess of potassium hydroxide. The presence of antimony is indicated by a black turbidity.—C. H. D.

Copper, Iodometric Titration of.—A special bottle for this titration, intended to avoid loss of liquid, is described by O. D. Neal.‡ When the iodate method is used, hydrogen cyanide is liberated, and particles of liquid are often ejected each time that the stopper is removed. In the new apparatus, the glass stopper is replaced by a rubber cork carrying

* *Zeitschrift für anorganische Chemie*, 1915, vol. xxi. p. 168.

† *Annales de Chimie analitique*, 1915, vol. xx. p. 229.

‡ *Journal of the American Chemical Society*, 1916, vol. xxxviii. p. 1308.

two tubes, one widened at the top to admit the iodate solution and the other as an outlet for vapour. In a second form, a single-bored cork is used, and a tube 8 mm. in diameter, widened at the upper end and drawn out and curved at the lower end, is perforated just below the cork. By shaking the bottle the last drop of iodate can be washed down.—C. H. D.

Copper-Tin Group, Electrolytic Separation of.—The use of hydrochloric acid solutions is proposed by E. P. Schoch, D. J. Brown and T. E. Phipps.* Sand's apparatus is used, and when tin, lead or antimony is being determined, the platinum cathode is first protected by a coating of copper. Antimony and tin are best stripped after the experiment by reversed electrolysis. The solution contains not more than 0.7 gm. of the metal, with 8-12 c.c. of concentrated hydrochloric acid and an equal volume of water. A little nitric acid may be added if necessary for solution, but the liquid must not be heated above 70° C. Two grammes of hydroxylamine hydrochloride are added to remove chlorine and oxides of nitrogen.

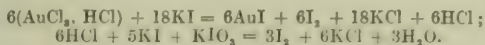
Tin is deposited rapidly and completely from such a solution. Tin may also be largely removed by electrolysis without a reducing agent, adding ammonium oxalate and oxalic acid only towards the end. Copper may be well deposited from the hydroxylamine reagent, provided that not more than 0.4 gm. per 100 c.c. is present.

For separations, the cathode potential is measured against a calomel electrode. To separate copper and tin, the cathode potential is first kept down to 0.4 or at most 0.5 volt, when the copper is deposited completely. After weighing the cathode, it is replaced in the solution, 2 grms. more of hydroxylamine hydrochloride are added, and tin is then deposited. Bismuth is deposited by using a very low cathode potential at first and raising it gradually. For antimony, more acid than usual must be employed, and the temperature must be kept between 50° and 75° C. If hotter, antimony is lost by evaporation, and if cooler, explosive antimony is deposited. Antimony or bismuth may be very conveniently separated from tin by this method. Lead is also easily deposited. The potentials of lead and tin are so close together that their separation is impracticable, but they may be deposited together. For their separation, the metals are attacked by nitric acid and potassium nitrate, the insoluble stannic oxide then being free from lead. Tin may be deposited at a potential which leaves lead in solution. Copper may be separated from antimony by electrolysis of a solution containing tartaric acid, but the antimony which remains in solution cannot be deposited quantitatively, and must be estimated by some other method. Several methods of depositing two or more metals simultaneously are also described.

Bismuth cannot be separated from copper by the method of graded potentials, but may be precipitated as phosphate.—C. H. D.

* *Journal of the American Chemical Society*, 1916, vol. xxxviii. p. 1660.

Gold, Iodometric Estimation of.—Gold chloride, according to L. Vanino and F. Hartwagner,* reacts with potassium iodide and iodate according to the equations:



The liberated iodine may be titrated with thiosulphate, 3 mols. of which correspond with one atom of gold. Gold chloride liberates iodine from potassium iodide alone, and the difference between this quantity of iodine and that set free when both iodide and iodate are present indicates the quantity of hydrochloric acid in the solution.—C. H. D.

Lead, Estimation of, as Sulphite.—A method is recommended by H. Pellet† in which the solution containing lead is neutralized with sodium hydroxide, just acidified with acetic acid, and saturated with sulphur dioxide. The lead sulphite is collected on a tared filter paper, washed, and dried.—C. H. D.

Lead, Volumetric Process for determining.—According to a method described by J. Waddell,‡ a gram. of the ore is warmed with 10 c.c. of hydrochloric acid, and evaporated to small bulk after addition of 5 c.c. of nitric acid. The liquid is mixed with an excess of ammonia and then with sufficient acetic acid to prevent precipitation of basic ferric acetate when nearly boiled. 10 c.c. of a 10 per cent. solution of potassium chromate are added, and the precipitated lead chromate is collected after 5 minutes. The precipitate is washed with boiling water, and then dissolved in 100 c.c. of dilute hydrochloric acid and returned to the original flask. The filtrate when cold is diluted to 200 c.c., mixed with 1 gram. of potassium iodide, and titrated with sodium thiosulphate run in slowly, a little starch solution being added towards the end. When the blue colour has nearly disappeared, 10 c.c. of concentrated hydrochloric acid are added, the solution is warmed to 40° C., and the titration is completed.

Where many other metals are present, the same method may be applied to lead previously precipitated as sulphate and redissolved in ammonium acetate.—C. H. D.

Lead Molybdate, Precipitates of.—The methods of precipitating lead molybdate in gravimetric analysis have been examined by H. B. Weiser.§ In solutions of salts of weak acids the precipitate is bulky, flocculent, and bluish-white in colour, and is then difficult to wash. In presence of nitric acid, or of an excess of an alkali acetate,

* *Zeitschrift für analytische Chemie*, 1916, vol. lv, p. 377.

† *Annales de Chimie analytique*, 1916, vol. xxi, p. 114.

‡ *Analyst*, vol. xli, p. 270.

§ *Journal of Physical Chemistry*, 1916, vol. xx, p. 460.

the precipitate is denser and yellowish-white in colour. The bulky precipitate retains some ammonium molybdate, and the transient darkening often observed during ignition is due to the decomposition of this salt.

For the estimation of molybdenum, the solution should contain a little free nitric acid, and is heated to boiling, a 4 per cent. solution of lead nitrate being added drop by drop from a burette with constant stirring, until a slight excess is present. As the precipitate is slightly soluble in nitric acid, the solution is now cautiously neutralized with ammonia, and a few drops of acetic acid are added. The precipitate is washed by decantation and then on an ashless filter with 2 per cent. ammonium nitrate, and after drying is separated from the paper, which is ignited separately.

The same method, but adding the solutions in the reverse order, is employed for the estimation of lead.—C. H. D.

Molybdate Precipitates, Recovery of.—Where large quantities of molybdenum residues accumulate, A. Grete* recommends that 4 volumes of the acid liquid be neutralized with ammonia and again acidified with one volume of the acid liquid. After heating, the yellow precipitate is filtered off, sulphuric acid is precipitated by barium nitrate, and the solution is made alkaline with ammonia and ammonium carbonate. After removing iron and alkaline earth compounds by filtration, the solution may be evaporated and the ammonium nitrate recovered. This contains some molybdenum, which is not harmful if the salt is to be used again for phosphorus estimations. Should it be necessary to remove it, yellow ammonium sulphide is added until the liquid is dark reddish yellow. The warm liquid is then cooled and cautiously mixed with dilute nitric acid until brown molybdenum sulphide separates, leaving a quite colourless solution.—C. H. D.

Nickel, Detection of, in Cobalt Salts.—As the characteristic precipitate of nickel glyoxime is not given in presence of a very large excess of cobalt, A. R. Middleton and H. L. Miller† have devised an improved method which allows of the detection of small traces of nickel in cobalt. Potassium cyanide is added to convert the metals into complex cyanides, only a small excess being used. Dimethylglyoxime is then added, followed by a dilute solution of silver nitrate, which either precipitates the cobaltcyanide or leaves it undecomposed whilst the nickelocyanide is decomposed and the nickel is then only able to give the characteristic reaction with the dimethylglyoxime. Only a small quantity of the latter reagent is required. The method is about five times as sensitive as regards nickel in cobalt as either of the modifications previously proposed.—C. H. D.

* *Chemiker-Zeitung*, 1916, vol. xl. p. 813.

† *Journal of the American Chemical Society*, 1916, vol. xxxviii. p. 1705.

Nickel, Estimation of.—A method for the separation of nickel from iron is proposed by T. L. Walker.* The solution of chlorides is heated and oxidized by the addition of hydrogen peroxide. It is then nearly neutralized with sodium carbonate, and red lead is added until there is a visible excess. Iron is completely precipitated. Lead and other metals may be precipitated from the filtrate by hydrogen sulphide, and nickel or cobalt is then estimated electrolytically. The method is inexact when applied to cobalt, much of the cobalt being carried down with the iron, but the results for nickel are stated to be as exact as when dimethylglyoxime is used.—C. H. D.

Palladium, Precipitation of.—In the course of an investigation of the catalytic action of palladium, it was noted by G. Scaliarini and G. B. Berti-Ceroni † that palladious compounds are readily oxidized to palladic compounds by the action of persulphates. When a solution of potassium palladochloride or palladobromide is heated with a persulphate, the corresponding palladichloride or palladibromide is precipitated. This reaction may be made use of for the separation of palladium from other metals.—C. H. D.

Precipitates, Changes in.—The changes in solubility and reactivity which take place in so many precipitates after their formation are reviewed by A. Villiers.‡ The fresh precipitates are termed "protomorphous," and the subsequent changes are usually accompanied by the development of heat. Sulphides exhibit these changes conspicuously. The sulphides of platinum, iron, nickel and cobalt pass rapidly into the less reactive form, that of zinc more slowly, whilst antimony sulphide is only transformed at the ordinary temperature in the course of years. The velocity increases with rise of temperature, but is still more sensitive to the influence of traces of other substances in the solution in contact with the precipitate. Sulphides may often be rendered crystalline by freezing the solution, which has the effect of greatly increasing the concentration of the solution.

Similar results are obtained with hydroxides.

A few applications are given. Nickel may be detected in presence of a very large excess of cobalt by adding tartaric acid and a large excess of potassium (not sodium) hydroxide. After saturating with hydrogen sulphide and filtering, the filtrate is colourless in absence of nickel, but coloured from brown to black if nickel is present.—C. H. D.

Silver, Electrolytic Method of determining.—It is found by E. P. Schoch and F. M. Crawford § that 99.6 per cent. of the silver in an ammoniacal solution of silver chloride may be deposited electrolytic.

* *Transactions of the Royal Society of Canada*, 1915 (iii.), vol. ix. p. 93.

† *Gazzetta chimica italiana*, 1916, vol. xlv. (ii.), p. 51.

‡ *Annales de Chimie*, 1916 (ix.), vol. v. p. 109.

§ *Journal of the American Chemical Society*, 1916, vol. xxxviii. p. 1682.

ally in a coherent form. This electrolyte has the advantage over cyanides of yielding a purer deposit. The conductivity of the solution must be increased by the addition of ammonium chloride, and a low current density must be used. With 0.2 to 0.5 grm. of silver, 20 g. of ammonium chloride may be used, the total volume being about 150 c.c., and the solution is electrolyzed at the ordinary temperature with about 0.35 ampere and 1.1 volt. Keeping the voltage constant until the current drops to zero gives a smooth deposit. The voltage is then raised to 1.3 or 1.4 and the process continued for another 25 minutes. To recover the remaining silver, 3 grms. of oxalic acid crystals are added without disturbing the solution, followed by enough hydrochloric acid to render the solution acid to litmus. Electrolysis is then continued for 20 minutes.—C. H. D.

Sulphides, Separation of.—For the separation of the metals which form sulphides insoluble in dilute acids J. Clarens * recommends neutralizing the acid solution, after removing silver and mercury (mercurosum), with ammonia. The liquid, which may now contain a precipitate, is mixed with its own volume of concentrated hydrochloric acid, warmed and cooled. Tin oxide, if present, is removed by filtration. The cold solution is then saturated with hydrogen sulphide.

The precipitate may contain copper, mercury, and arsenic. It is washed with hydrochloric acid (1 : 2) saturated with hydrogen sulphide, and then with water. It is then extracted with 10 per cent. potassium hydroxide solution, which leaves copper and mercury but dissolves arsenic. A small quantity of mercury which passes into solution may be removed by repeating the treatment. Copper sulphide is dissolved by means of nitric acid (1 : 1).

The filtrate obtained from the sulphide precipitation in the cold is now saturated hot. Some arsenic may be precipitated. The filtrate is boiled and diluted with its own volume of water. Tin and bismuth are now precipitated by passing hydrogen sulphide, and separated by means of potassium hydroxide. The filtrate is boiled, neutralized with ammonia, just acidified with hydrochloric acid, and again saturated while cold with hydrogen sulphide. Lead and cadmium are precipitated, and may be separated by nitric acid.—C. H. D.

Tellurium, Separation from Arsenic.—Separation of these elements by means of magnesia mixture being always incomplete, P. E. Brown-ing, G. S. Simpson and L. E. Porter † recommend that the tellurium be first removed by reduction with sodium sulphite in dilute hydrochloric acid solution in presence of potassium iodide. The filtrate is boiled to remove sulphur dioxide, mixed with hydrogen peroxide and boiled to remove iodine, made alkaline with sodium hydroxide, and hydrogen peroxide again added to convert arsenic to arsenate.—C. H. D.

* *Bulletin de la Société chimique*, 1916 (iv.), vol. xix. p. 154.

† *American Journal of Science*, 1916 (iv.), vol. xlii. p. 106.

Tin, Separation of.—An improved method of separating tin, arsenic and antimony is proposed by J. M. Welch and H. C. P. Weber.* The precipitated mixed sulphides from the ammonium sulphide separation are drained by the filter-pump, and heated for 10 minutes on the steam bath with 10 c.c. of concentrated hydrochloric acid. Arsenic sulphide remains undissolved and is collected as usual. The filtrate is diluted to 20 c.c. and saturated with hydrogen sulphide. As the solution cools, the precipitate becomes brown, and the depth of the colour indicates the relative proportions of tin and antimony. The whole is then heated until the excess of hydrogen sulphide is driven off. Five c.c. of 3 per cent. hydrogen peroxide are added, and the solution is heated until the precipitate redissolves. After adding 5 to 10 gms. of oxalic acid, the solution is again saturated while hot with hydrogen sulphide, which precipitates the antimony. To detect tin in the filtrate, a portion is boiled with granulated assay lead, which reduces it to the stannous condition. It is rapidly cooled and filtered into mercuric chloride solution, a precipitate of mercurous chloride indicating the presence of tin.—C. H. D.

Tin, Volumetric Methods for.—The volumetric methods for the estimation of tin are reviewed by R. L. Hallett.† All the methods which have proved satisfactory depend on the oxidation of stannous to stannic salts in acid solution, with the exception of one which involves the oxidation of sodium stannite to stannate in alkaline solution. The simplest and most accurate method is that of titration with iodine in cold hydrochloric acid, but opinions differ as to the most suitable reducing agent. Sheet nickel is stated to be the best, and the method is then independent of the presence of most other metals, unless present in such large quantities that their colour masks the end-point. The reduction must be performed in an atmosphere of carbon dioxide, in a solution containing not less than 25 per cent. or more than 40 per cent. of free concentrated hydrochloric acid. Stout sheet nickel rolled into a coil so that it will hang in the flask is used, and the solution is gently boiled for 30 minutes, until the yellow colour changes to pale green. It is then cooled to 22° C. and titrated with standard iodine. If much antimony is present, a more strongly acid solution must be used, or else the antimony is precipitated in a slimy mass, which obscures the end-point.—C. H. D.

Tin Ashes, Analysis of.—Ashes and similar material containing tin may be analyzed by the following method given by N. Welwart.‡ From 3 to 10 g. of the sample are boiled with 30 to 100 c.c. of nitric acid (1·2), and when the action is over, diluted to 3 or 4 times the volume of the liquid with boiling water and filtered. The precipitate, after

* *Journal of the American Chemical Society*, 1916, vol. xxxviii, p. 101.

† *Journal of the Society of Chemical Industry*, 1916, vol. xxix, p. 1087.

‡ *Chemiker-Zeitung*, 1916, vol. xl, p. 458.

drying, igniting and weighing, is fused with sodium hydroxide and sulphur (2:1), dissolved in hydrochloric acid, boiled, and reduced by pure antimony in an atmosphere of carbon dioxide, after adding 25 c.c. of hydrochloric acid. After cooling, the solution is titrated with N/10 iodine solution which has been previously standardized against a solution prepared from pure tin by dissolving in concentrated sulphuric acid, adding hydrochloric acid and reducing with antimony as above. The accuracy of the method is not affected by the presence of lead, copper, or zinc.—C. H. D.

Tungsten, Estimation of.—For most materials containing large proportions of tungsten, E. Dittler and A. von Graffenried * recommend very fine grinding in a steel mortar and sifting through the finest muslin. About 0.2 gm. is then treated with bromine (without water) for 24 hours. Only silica should remain insoluble. The solution is then evaporated nearly to dryness with 10 c.c. of hydrochloric acid, and then a few c.c. of hydrochloric and concentrated nitric acids are added. After 2 hours the yellow, crystalline precipitate of tungsten trioxide is collected, washed until the washings are free from iron, and ignited. Should tin be present, the tin and tungsten oxides are separated by ignition with ammonium chloride.

Mixed tin and tungsten ores are analyzed by fusing 1 gm. with 6 or 8 grms. of sodium peroxide in an iron crucible. The cooled mass is dissolved in water and made up to 500 c.c. 250 c.c. of this are taken for the estimation of tungsten by the mercurous nitrate method. Another 200 c.c. are mixed with a concentrated solution of 10 grms. of sodium phosphate and acidified. Any precipitate is removed by filtration, and the filtrate is boiled, saturated while hot with hydrogen sulphide, diluted, and again saturated. The precipitated tin sulphide is washed with ammonium acetate solution and dried, and the tin estimated by any of the usual methods. All tungsten passes into the filtrate.—C. H. D.

Vanadium, Estimation of.—According to G. Edgar,† vanadium is readily reduced from the quinquevalent to the quadrivalent condition by the action of metallic silver. The solution must be acidified with sulphuric acid. The vanadium may be determined quantitatively in three different ways: (a) gravimetrically, by the loss in weight of the silver used for reduction; (b) volumetrically, in the usual manner by permanganate; (c) by thiocyanate titration of the dissolved silver. All give very accurate results.

Slightly acid solutions of vanadates, according to W. A. Turner,‡ are readily precipitated by cupferron (ammonium salt of nitroso-phenylhydroxylamine). A solution containing 0.000004 gm. of

* *Chemiker-Zeitung*, 1916, vol. xl. p. 681.

† *Journal of the American Chemical Society*, 1916, vol. xxxviii. p. 1297.

‡ *American Journal of Science*, 1916 (iv.), vol. xli. p. 339, and vol. xlii. p. 109.

vanadium per c.c. gives a distinct red coloration. A slight excess of cupferron is added and the precipitate, after washing with 1 per cent. sulphuric acid containing a little cupferron, is cautiously ignited in a platinum crucible to vanadium pentoxide.

This method may be used to separate vanadium from phosphoric and arsenic acids. The separation from uranium is not perfect, but the precipitate may be redissolved in ammonia, very cautiously acidified, and again precipitated.—C. H. D.

Zinc, Sulphide Titration of.—A critical study of the sodium sulphide method for the volumetric estimation of zinc by J. Patek * shows that the results are not affected by the presence of ammonium salts, and that it is immaterial which acid is used to dissolve the metal. The solution under examination and that used for comparison need not necessarily contain the same proportion of zinc.—C. H. D.

II.—TESTING.

Alternating Stresses, Endurance of Metals under.—Tests for the endurance of metals under alternating stresses fall, under present-day conditions, into the category of experimental research owing to the length of time taken.

In the experience of B. Parker Haigh,† the performance of steels as regards resistance to fatigue is generally better than that of alloys of comparable strength.

The hope is expressed that a relation will eventually be found between the limiting range of stress above which fatigue is liable to occur, and the other physical properties of the metal; so that the fatigue limit may be deduced from the ordinary proving tests without carrying out the lengthy tests under alternating stress.

The testing machines used in researches with alternating stress differ chiefly in the kind of stress applied, viz.: alternations of direct tension and compression, torsion, plane bending and rotary bending. A brief description of some of the devices used by Woehler, Baker, Sankey and Arnold is given. High-speed machines have been devised by Professors Reynolds and Hopkinson.

In a novel form of testing machine devised by the writer (Dr. Haigh) an alternating current magnet is employed to generate the whole of the pull applied to the test-piece without the agency of resonance. A description is given of such a machine installed in the Engineering Laboratory of the Royal Naval College, Greenwich. The machine is

* *Zeitschrift für analytische Chemie*, 1916, vol. lv. p. 427.

† *Mechanical World*, April 1916, vol. lix. p. 177.

fitted with two-phase magnets so that specimens may be tested under stresses ranging between equal intensities of tension and compression. Provision is also made for testing specimens under combined stresses, an alternating stress being then applied simultaneously with a steady load of tension or compression. A diagrammatic view of the machine is shown. The two magnets alternately attract the armature upwards and downwards respectively, the pull of the one being at its maximum when the pull of the other is zero. The armature is coupled to the lower end of the specimen, of which the upper end is held in an adjustable fitting attached to the framework carrying the magnets. The inertia force required for the acceleration of the armature is provided by a spring connected between the armature and the frame and adjustable in stiffness according to the frequency at which it is desired to carry out the test. By extending or compressing this spring, the specimen is subjected to a steady load of tension or compression in addition to the alternating stress produced by the magnets. In operating the machine, the position of the upper end of the specimen is adjusted so that the air-gaps between the armature and the two magnets are equal, this being indicated when the currents taken by the two magnets are the same.

The pull is measured by the voltages induced in secondary coils wound close to the pole faces, the machine being standardized in a special manner by means of a cylindrical phosphor-bronze specimen fitted with an extensometer.

The cyclical variation of the load on the specimen may be studied by watching the vibration of the index levers of the extensometer, a stroboscopic disc being interposed between the vibrating index levers and the objective of the microscope. The disc is described.

The specimens used were turned with short cylindrical portions about $\frac{1}{2}$ inch in length at the wide part of their lengths, and were tapered towards the ends, with gradual transition curves between the conical and cylindrical portions.—F. J.

Brinell Hardness of Non-ferrous Metals.—Some applications and limitations of the Brinell Hardness testing of non-ferrous metals are described by Hugo Friedmann.* Some of the results given are only negative, but they serve to indicate the uses which can be made of this method of testing as a control on manufacture.

As a method of testing castings in brass, bronze or aluminium the test is somewhat difficult and unreliable. The impressions have generally very rugged edges which are difficult to measure, and an average value of three of four measurements must generally be taken. The author has attempted to trace a connection between these irregularities and the crystalline structure of the metal, by examining impressions made in previously polished and etched specimens, but is

* *Metal Industry*, Aug. 25, 1916, vol. ix. No. 8, p. 236.

unable to trace any relation. He observed the irregularities on annealed and unannealed castings, but not on material which had been subjected to mechanical deformation, with or without subsequent annealing. He suggests that they are due to minute holes in the metal. Neither explanation, however, suggests a means of eliminating the difficulty. Castings may have different hardness in different parts, owing to differences in the speed at which the metal cools, and this suggests one use to which the Brinell method may be put.

The test may be used for sorting castings of similar appearance which have been accidentally mixed, where it has the advantage that it does not interfere with the subsequent use of the pieces.

The hardness testing may be used as a check on the mechanical and thermal treatment of metals. The investigation of different methods of annealing, of the influence of time and temperature on annealing may be determined by this means, while as a check on the processes of manufacture in the factory, more especially where the processes are practically continuous and where a definite standard must be maintained, the test may be of considerable value.

Interesting results have been obtained from the examination of the hardness at different depths from the surface of cold-drawn copper rod, and very considerable differences have been found between the outside and the centre in bars which have been reduced only slightly in diameter. When these differences become too great the internal stresses in the metal will set up spontaneous cracking, and it is suggested that the use of hardness testing in the mill on the finished rods may form an effective check on manufacture.

In the production of cold-rolled sheet it is frequently found that the impressions are elliptical in shape if the metal has been subjected to deformation in one direction only, and hardness testing may afford an indication of the amount of cold work on the metal.

It is pointed out that the Brinell method cannot be used for determining resistance to wear, and results are given to support this view.—
D. H.

Standard Test Specimens of Cast Zinc Bronze.—The bulletin issued by the U.S.A. Bureau of Standards covering an investigation by C. P. Karr and H. S. Rawdon* on test-bars made from a mixture of copper 88 per cent., tin 10 per cent., and zinc 2 per cent. is discussed.

As a result of the experiments it is shown to be possible to obtain specimens, cast to size in sand and poured within a range of temperature from 1120° C. to 1270° C., which will possess a tensile strength of 16·5 tons per sq. in., an elongation of 15 per cent. (on 2 inches) and a reduction of area of 14 per cent.

The results of the investigation are summarized as follows:—

* *The Foundry*, June 1916, vol. xlv, p. 229.

1. For a sand-cast test-bar the cast-to-size shape is the best.
 2. Greater uniformity of strength and ductility is secured by pouring within the temperature range above-mentioned.
 3. Dry-sand moulds are recommended and may be either horizontally or vertically arranged for pouring. Economy of time and labour is achieved in the former method but no superiority in technical results.
 4. Results of equal value may be obtained from chill-cast bars annealed at from 500° to 700° C. and the best sand-cast bars. The former are easily produced, but are expensive to machine and give misleading results. The latter (cast-to-size shape) are recommended for adoption as standard for general foundry practice.
 5. An increase in ductility is obtained by annealing, which, in the temperature range of 600° to 700° C., has a marked effect on the deformation produced by continuously increasing loads on specimens.
 6. Chill-cast specimens, annealed between 500° C. and 700° C., are considered to be comparable in results with the sand-cast bars.
 7. The average density of sand-cast specimens is 8.58 and of chill-cast specimens 8.6.
 8. The elastic limit of this bronze varies from 6.7 to 7.6 tons per sq. inch.
 9. Cooling curves show the melting point of the alloy to be 980° C., and two transition points, one at 780° C. and a feebler one at 530° C.
- F. J.

Strain-meter.—An account is given of an instrument which has been placed on the market in America for observing strains and determining stresses under actual working conditions in structural members of ships, bridges, cranes, and slowly reciprocating machinery.* The instrument is attached to the plate, girder, &c., by means of two $\frac{3}{8}$ -inch studs. These two studs carry rods which lie parallel to the axis of measurement. One rod carries a chamber communicating with a glass capillary gauge tube. This chamber is closed on one side by a flexibly mounted diaphragm against the centre of which the second rod bears. The chamber is filled with a coloured liquid until the latter stands at a convenient height in the gauge tube. Any motion between the two points of attachment, due to change in length, is communicated by the rods to the diaphragm and shown to a greatly enlarged scale by the rise or fall of the liquid in the gauge tube. In the standard pattern the multiplying ratio is about 500. A specially sensitive instrument is made for laboratory use.—S. L. A.

* *Metallurgical and Chemical Engineering*, May 1916, vol. xiv (No. 9), p. 550.

III.—PYROMETRY.

Calibration, Fixed Points for.—The Reichsanstalt at Charlottenburg, according to E. Warburg,* intends to observe the following rules in the calibration of thermometers and pyrometers:

The boiling point of sulphur is to be taken as

$$444.55^{\circ} + 0.0908(p - 760) - 0.000047(p - 760)^2$$

where p is the reduced barometric pressure. Between the boiling points of water and sulphur the instruments are to be compared with the platinum resistance thermometer. Within this region the following fixed points are proposed:

	°C.
Freezing points, Mercury	-38.89
Tin	+231.84
Cadmium	320.9
Zinc	419.4
Transformation point, Sodium sulphate	+ 32.38
Boiling points, Naphthalene	217.96 + 0.058 ($p - 760$)
Benzophenone	305.9 + 0.063 ($p - 760$)

Below the freezing point of mercury a platinum resistance thermometer is to be used, which has already been compared with the hydrogen thermometer. Two boiling points are used:

Carbon dioxide	$-78.5^{\circ} + 0.01595(p - 760) - 0.000011(p - 760)^2$
Oxygen	$-183.6^{\circ} + 0.01258(p - 760) - 0.0000079(p - 760)^2$

Above the boiling point of sulphur, the following freezing points will be used:

Antimony	630°
Silver	960.5°
Gold	1063°
Copper	1083°
Palladium	1557°
Platinum	1764°

Interpolation between these fixed points will be effected by means of a thermo-couple composed of platinum and 10 per cent. rhodium-platinum. This scale is in agreement with the radiation scale, on which two temperatures t_1 and t_2 are related to the corresponding intensities H_1 and H_2 of the homogeneous black body radiation of wave length λ by the formula:

$$\log \text{nat} \frac{H_2}{H_1} = c \left\{ \frac{1}{273 + t_1} - \frac{1}{273 + t_2} \right\},$$

c being taken as = 14300.

These higher temperatures, determined optically, are somewhat higher than those determined by the gas thermometer.—C. H. D.

* *Berichte der deutschen chemischen Gesellschaft*, 1916, vol. xlix, p. 474.

Photometric Method, Fixed Point for.—Owing to the difficulty of realizing the Violle standard of luminosity, H. E. Ives * calls attention to the proposal of Waidner and Burgess to use the emission of the black body at the melting point of platinum. He recommends, however, that instead of making it the unit of luminosity, it should be a fixed point on a luminosity scale, preferably that scale whose unit is the watt of luminous flux.—C. H. D.

* *Physical Review*, 1916 (ii.), vol. viii. p. 250.

FURNACES AND FURNACE MATERIALS; FOUNDRY METHODS AND APPLIANCES.

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I.—FURNACES AND FURNACE MATERIALS.

Electric Arc Furnace for Laboratory Use.—An account of the construction and performance of a small arc furnace for melting charges of 10 lb. of iron or steel is given by O. P. Watts.* Required of tilting type, it was necessary to economize weight. The body, $16\frac{1}{2}" \times 14\frac{1}{2}" \times 17\frac{1}{2}"$ high, was cased in sheet steel $\frac{1}{8}"$ thick. The refractory material employed was magnesia, whilst for heat insulation air-slaked lime was used. Two inches of air-slaked lime was tamped on the bottom of the furnace and on this the melting pot, $8\frac{3}{4}" \times 6" \times 7"$, was built up of magnesia brick $2\frac{1}{4}"$ thick, corners being filled with a cement made of electrically fused magnesia and a sodium silicate binder. The space, 2 to 3 inches in width, between the pot constructed as above and the walls of the furnace was filled with air-slaked lime. The roof, which presented some difficulty, was finally satisfactorily constructed of a single slab of electrically fused magnesia $11" \times 8" \times 2\frac{1}{4}"$ thick, weighing 20 lb., covered with 2" of lime. The furnace was poured from a spout projecting from the middle of one side. The space between pot and spout was bridged and roofed with fused magnesia. The electrodes of $1\frac{1}{2}"$ round carbon, hand-adjusted, carried in water, cooled, split, and screwed brass holders, passed via magnesia tubes through the roof slab so as to meet at an angle of 90° above the charge. The furnace, charged through the spout, was always heated before introducing the charge. When hot, 25 kws. at 80 volts melted 10 lb. of iron in 24 minutes.—S. L. A.

Electric Furnaces.—In a general review of electric ovens and urnaces, W. R. Conover † discusses electric annealing and smelting

* *Metallurgical and Chemical Engineering*, June, 1916, vol. xiv. (No. 12), p. 681.

† *American Machinist*, Sept. 1916, vol. xlv.

furnaces. In outward appearance the former resemble the usual type of gas or oil-fired furnace, being constructed of iron framework and firebrick with an interior lining of highly refractory brick. The furnace equipment includes a control panel main and auxiliary carbon electrodes and regulating transformer. A layer of several inches of foundry coke (reduced to proper size) upon the refractory floor constitutes the main resistor. Special refractory material built into the arch roof of the furnace composes the auxiliary resistor, which becomes an electrical conductor when acted upon by the heat radiated from the main resistor. Current reaches the coke resistor through carbon electrodes located at each side of the furnace in pockets filled with pulverized carbon, which prevents a high resistance arc and lengthens the life of the electrodes by preventing oxidation.

A neutral or oxidizing atmosphere may be obtained, oxygen being eliminated from the interior of the closed furnace by the carbon resistor. Ventilation may then be controlled to produce the required kind of atmosphere. The control is practically automatic, maintaining a uniform temperature throughout the process.

In electric smelting furnaces, heat is developed either by passing current through arc electrodes, using the heated gases of the arc as a resistor; by passing current through the charge, the molten slag acting as conductor and heat being generated as the current passes through the molten mass; or by passing current through a carbon resistor.

The current is usually alternating, being transformed from high to low voltage.

The factor of efficiency of the electric smelting furnace is stated to be from 2 to 30 times that of the usual type of metallurgical furnace. It may range as high as 60 to 85 per cent., being generally much higher than it is in ordinary foundry furnaces and cupolas.

The range of available temperatures has been increased and now runs from 1800° C. to 3600° C., a temperature not attainable in the fuel-fired furnace, whilst the elimination of air or injurious gases increases the efficiency and renders the electric furnace adaptable to the production of substances such as zinc and phosphorus.

The cost is in general greater than for coal or coke furnaces, but in localities remote from coalfields, or where freight rates are high and where water power is abundant, the electric furnace presents distinct economic advantages when its high rate of efficiency is considered.—F. J.

Furnaces and Stoves, Gas and Oil-fired.—A large number of furnaces and stoves being now extensively employed in connection with the production of munitions is illustrated and described.* Furnaces for heating, annealing, hardening and similar processes are included.—F. J.

* *Mechanical World*, June 1916, vol. lx.

II.—*FOUNDRY METHODS AND APPLIANCES.*

Brass Chips, Melting.—A series of hints is given* regarding the economical melting of brass chips, and it is claimed that by observing proper precautions the loss of metal should not exceed 5 per cent.

The use of a charging funnel, a large crucible, and of plenty of charcoal is advocated.

A "button" of metal should be left in the crucible after pouring to serve when re-melted as a bath into which the subsequent addition of chips will dissolve with a minimum amount of oxidation.—F. J.

Cartridge Brass, Manufacture of.—The production of 70 : 30 brass for the manufacture of cartridge cases is the subject of an article.† The question of impurities and of general foundry practice is discussed at some length.

Only the best brands of copper and zinc should be used in the manufacture of cartridge brass. Antimony and tin are stated to be the most undesirable impurities, and should not be present in anything but the most minute traces. Iron, lead, bismuth and arsenic, though deleterious, are permissible if they do not occur in percentages greater than 0.15, 0.10, 0.006 and traces respectively.

The effect of traces of antimony is to make the metal brittle and to set up incipient cracking during the rolling and stamping operations. Arsenic, though less powerful in character, has a similar action. Iron renders the brass hard and tough and increases the mechanical difficulties. Lead even in moderately small quantities is undesirable, since it is very liable to segregate and produce local weakness.

For melting, a charge consisting of 50 per cent. virgin metal and 50 per cent. scrap is said to be suitable. The copper should be first charged in, the zinc and scrap being added when this is run down. Calcined borax, salt and occasionally Chili saltpetre are used as fluxes, frequently in conjunction with charcoal. Carbon rods should be used for stirring.

Considerable attention is given to the question of the preparation of the mould. A variety of oils are used for dressing, generally with powdered charcoal or graphite, and these should be applied thinly with a brush. The production of sound ingots, with a good surface, suitable for rolling into strip, is almost impossible unless the preparation of the moulds is satisfactorily carried out.

The temperature of the metal at the moment of pouring should be sufficiently low that the evolution of gas during solidification in the mould is reduced to a minimum, but not so low that it will solidify on striking the mould, with the production of "cold shuts"; skimming is

* *Mechanical World*, Oct. 1916, vol. lx. p. 173.

† *Metal Industry*, Aug. 4, 1916, vol. ix. No. 5, p. 149.

necessary while the metal is being poured, to prevent the entrance of dross into the mould, but it is recommended that iron skimmers be avoided for this purpose.—D. H.

Chemist in the Brass Foundry.—In a paper read by R. T. Rolfe,* the necessity for and value of the chemist in the brass foundry is shown.

The desirability of employing pure brands of metal is emphasized, failures to meet Admiralty specifications for cast gun-metal being attributed to lack of knowledge of the composition of the metals used rather than to methods of casting. Analyses of commercial brands of tin are given, showing that nearly 1 per cent. of impurities may be added by using an impure brand of tin. Lead increases the liability of Admiralty gun-metal to corrosion.

The influence of arsenic on gun-metal is shown in the following table :

Copper.		Gun-metal Cast from same.			
Brand.	Percentage of Arsenic.	Average Yield Point. Tons per Sq. In.	Average Ultimate Tensile Strength. Tons per Sq. In.	Average Elongation per Cent.	No. of Samples tested.
1	trace	11.2	16.6	14.3	114
2	0.30	10.7	15.5	12.4	172
3	0.75	11.2	14.4	7.4	10

The author refers to the alpha and delta eutectoid as eutectic, and unfortunately appears to consider that the inversion point at 500° C. is an eutectic freezing point. He also assumes arsenic to be a deoxidizer in copper, which is an incorrect assumption.

The influence of casting temperature on mechanical properties was studied, a list of results being given as follows :

No.	Casting Temp. Degrees C.	Yield Point. Tons per Sq. In.	Ultimate Stress. Tons per Sq. In.	Elongation per Cent.
1	1200	11.3	17.8	18
2	1200	10.9	18.1	20
3	1150	12.4	18.6	17
4	1150	12.2	18.0	20
5	1100	11.5	18.3	16.5
6	1100	11.0	19.1	22
7	1050	12.4	18.2	16
8	1050	11.9	16.6	10

Little difference was observed in the microstructures. The usual temperature for pouring is 1200° C.

* *Proceedings of the British Foundrymen's Association*, 1914-15, p. 88.

It is shown that the metal in the neighbourhood of blowholes caused by steam and gases from the mould shows a structure similar to that of a "chill" casting, whereas that in the neighbourhood of holes caused by the liberation of gases from the metal does not show such structure.

The question of bearing metals is discussed and the microstructure, composition and suitable uses of phosphor-bronze, copper-tin-antimony, lead-antimony, and lead-tin-antimony alloys are described. Importance is attached to crystal-size and uniform distribution of constituents, particular care being required to prevent the segregation of lighter crystals, e.g. Sb-Sn cubes to the top of a solidifying casting.

A phosphor-bronze alloy used for dynamo and motor bearings consists of 85 per cent. copper, 14.4 per cent. tin and 0.6 per cent. phosphorus. Particulars are given of a white metal consisting of 80 per cent. lead, 10 per cent. tin and 10 per cent. antimony.—F. J.

Copper, Refining of.—The refining of copper by means of the injection under suitable pressure of hydrocarbon oil, is the subject of an invention described by Edward C. King.* It is claimed that the process is applicable to existing furnaces of any type, provided that they are so constructed that the large volume of gases evolved during the treatment can escape. The hydrocarbon oil, preferably crude petroleum, is introduced into the metal through a tube, which can be immersed to any required depth below the surface. The end of this tube is protected by means of a refractory covering. It is stated that the oxygen is the last impurity to be expelled, the other impurities being first removed, and that the method thereby avoids the exposure of the molten metal to any preliminary oxidizing atmosphere to remove these other impurities. The actual nature of the other impurities which it is possible to remove by this means is not stated, nor is any indication given of the nature of the reactions by which they are removed.—D. H.

Crucibles, Care of.—Since the beginning of the war the securing of the best clays in sufficient quantity has troubled the crucible maker, and made it impossible to supply the highest grade crucibles.†

Greater care must be given in annealing. Smaller crucibles should be used than those the foundry has been in the habit of using.

The native clays now used by crucible makers have made the crucibles more frail than was the case with the foreign clays—more likely to crack on sudden heating and cooling.

Crucibles should not be cooled down too rapidly; they should be returned, after the day's work is done, to the furnace to cool down slowly with it.

The smaller the crucible the greater the number of heats obtainable from it.—S. L. A.

* *Metal Industry*, July 28, 1916, vol. ix. No. 4, p. 112.

† *Metallurgical and Chemical Engineering*, June 1916, vol. xiv. (No. 11), pp. 666-7.

Die Castings, Data on.—The strongest feature of the die-casting is stated by J. A. Schultz * to be its competition with machine work. In ordinary practice, die-castings are made to dimensions of plus or minus 0.001 inch to each inch of dimension. Provision for shrinkage is one of the most important details in the production of die-castings. In a zinc-base alloy the shrinkage is 0.004 inch per inch of dimension, this indicating the care required in making the dies or moulds, which are made of special alloy machinery steel. The cost of the dies is very considerable, but upwards of 100,000 duplicate castings, each accurate, may be made from a properly constructed die, thus making the die-cost per casting small.

The soundness of castings is determined by using a perfect casting as a standard and weighing subsequent castings against it. This method will detect the presence of the smallest blowhole.

The mixtures used, the reinforcement of parts subjected to severe strain, by means of pins, bushings, &c., and the advisability of cutting threads in small holes rather than casting them in, were dealt with. Plain holes from 0.01 inch diam. and upwards could be successfully produced in the casting.

Doubt was expressed as to the commercial practicability of producing die-castings in brass. The machines used were the plunger or the hydraulic type (in which the metal in the pump cylinder is under pressure only at the time of casting), the air type (in which there is a constant pressure on all the metal contained in the pot) and the centrifugal machine (in which the metal is made to fill the mould by centrifugal force). The plunger type was the most popular.

In the ensuing discussion, it was stated that dies were surface-treated, only to improve the appearance of the casting. The castings themselves, however, could be plated, enamelled, &c. The temperatures of the dies and of the metal varied with the different alloys used, so as to assist in controlling shrinkage.

Duplication of castings in the same die depended largely on the number of cores to be withdrawn. In some moulds 40 or 50 impressions of small plain castings were made. A pressure of about 1000 lb. per sq. in. was applied to the molten metal in the die. This high pressure involved the secure locking in position of the cover.—F. J.

Manganese Brass, Manufacture of, from Scrap.—The use of non-ferrous scrap metal of varying compositions for the manufacture of manganese brass is dealt with by Lieut. J. B. Rhodes.† The only metal available for such purposes is alloy scrap of considerable purity, but in arsenals and naval yards considerable quantities of naval brass, cartridge metal scrap and manganese brass, in the form of skimmings, turnings and trimmings, accumulate and it is to dispose of these accumulations that the following method has been devised.

* *Mechanical World*, June 1916, vol. ix. p. 23.

† *Metal Industry*, Aug. 18, 1916, vol. ix. No. 7, p. 213.

In the first place a special "hardener" is made, which is the secret of the whole process. This may be made to varying compositions, but the following has been found satisfactory: 25 lb. mild steel and 25 lb. ferro-manganese (80 per cent.) are melted together, and 100 lb. copper, generally in the form of wire or other scrap, added as fast as the mixture will take it. Great care should be taken to skim the pots, which are usually poured into a ladle for casting. It is found that the carbon is practically all eliminated during the melting and separates out on top of the metal. The resulting alloy is cast into ingots, which can be readily broken up into pieces of any desired size.

The composition arrived at was: copper, 57 per cent.; zinc, 40 per cent.; iron, 1 per cent.; manganese, 0.75 per cent.; aluminium, 0.75 per cent.; tin, 0.50 per cent. In melting, the most difficult scrap to melt should be charged first, though all but the additions may be charged at once. As soon as this is melted the hardener is added. Any remaining scrap is then charged, and after the heat is well up the zinc is added, then tin if necessary, and finally aluminium. This is stirred well and then tapped. Small ladles are generally used for pouring. The costs of this method are high on account of the labour in pouring, but the total charges should not exceed 2 cents per lb.

The quality of the metal thus produced is good, and quite frequently 75,000 lb. per square inch and 20 per cent. elongation are obtained on sand castings.—D. H.

Sand-Blasting and Sand-Blast Machines.—In a paper to the Birmingham Association of Mechanical Engineers, J. J. Richardson* describes the uses of the sand-blast, emphasizing the economy effected in machining castings which have been sand-blasted.

The advantages of the sand-blast barrel over the ordinary rattler are discussed as follows:

1. Complete freedom of castings, &c., treated in barrel, from sand and scale.
2. Complete exposure of surface even of intricate cored castings to sand-blast.
3. Preservation of sharp outlines of the work, owing to slow rate of revolution of barrel and shortness of the operation.
4. Greater capacity and therefore saving of floor space.
5. Operation free from dust.—F. J.

Venting Permanent Moulds.—The removal of gases and air from permanent (metal) moulds has engaged the attention of W. J. May,† who advocates the employment of permanent moulds for suitable articles, with the object of economizing in cost of production.

With some shapes, a pouring cup can be arranged in a sand portion

* *Mechanical World*, Oct. 1916, vol. ix. p. 100.

† *Ibid.*, vol. ix. p. 227.

of the mould. [This arrangement had previously been recommended.* — *Note by Abstractor.*] Sound castings could only be obtained in sand or metal moulds if the molten metal was clean and free from dirt.

A mould for a wheel casting is illustrated and described. The mould is in three horizontal sections, the centre one being divided vertically into three parts. At $\frac{1}{2}$ inch from the edge of the mould, a $\frac{1}{4}$ -inch circular groove is cut and 4 or more straight grooves connecting this with the outside of the mould. Saw cuts communicate from the mould to the circular groove, and thus air and gases have a free means of escape.

Sand cores, well blacked and polished, may be used, but must be vented and readily compressible and must be in communication with vents in the metal mould at both ends. Doubt is expressed as to the desirability of having cores. The holes have to be bored out anyhow, and if more scrap is produced by boring from the solid it is clean scrap.

All vents should taper from the inside of the mould, otherwise difficulty will be experienced in extracting metal that may find its way into them. Gas-producing substances should not be used in the mould or core dressings, the tendency being for such gases as are formed to be occluded in the surfaces of the castings. Other points to observe are rapid melting, pouring of clean metal free from oxide and gases, continuous operation in order to keep moulds in good casting condition and the use of a flux, e.g. chloride of zinc. The use of the "Salamanca" plumbago plunger-stirrer is described.—F. J.

White Metal Borings, Recovery of.—The separation of bronze and white metal scrap is a difficult task, but a method of accomplishing this is described by G. Frederick.†

The device depends on the difference in melting point of the two alloys. It is simply a furnace covered at the top with a stout inclined cast-iron plate fitted with two sides. The top of the plate is grooved with a close series of flutes or channels running down the incline. The turnings and borings are thinly spread on the inclined plate, which should be as steep as possible, without however permitting the turnings to roll down. The temperature of the furnace is maintained until the white metal just melts, when the liquid globules collect and run down the inclined channels, at the bottom of which they are collected in a suitable way. The remaining copper alloy is of course somewhat oxidized and contaminated with small quantities of white metal which adhere to it. It will, however, sell as scrap.

The white metal thus recovered is quite suited for bearings of lesser importance, but should not be used for the better classes of work without being analyzed and made up to a suitable composition by remelting.—D. H.

* F. Johnson, "Non-Ferrous Alloys in Chill Moulds," *Metal Industry*, March 1916, p. 86.

† *Metal Industry*, July 21, 1916, vol. ix. No. 3, p. 71.

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Tin, in the following Shapes:—Square, Round, Hexagon, Octagon, three Square, half Round, Cubes, Balls, Plates, Strips and Discs—The following Metric Equivalent Tables—French, Russian, Austrian and Rhenish Lines to Mm.—Rhenish Inches to Mm.—Inches and Fractions to Decimals of a Foot—Troy Ounces to Decimals of a Pound Troy—Avoir. Oz. and Lb. to Decimals of a Lb.—Inches and Fractions to Mm.—Mm. from 1 to 2000 and Meters 2 to 60 to 64ths of Inch—Oz. and Lb. Avoir. to Kilograms—Kilograms to Oz. and Lb. Avoir.—Drams and Oz. Avoir. to Grammes—Oz. and Lb. Troy to Grammes—Grains Troy to Grammes—Lb. Avoir to Lb. Troy—Russian Funts and Poods to Lb. Avoir. and Kilos—Oz., Drams, and Fractions to Oz. and Decimals of a Lb.]

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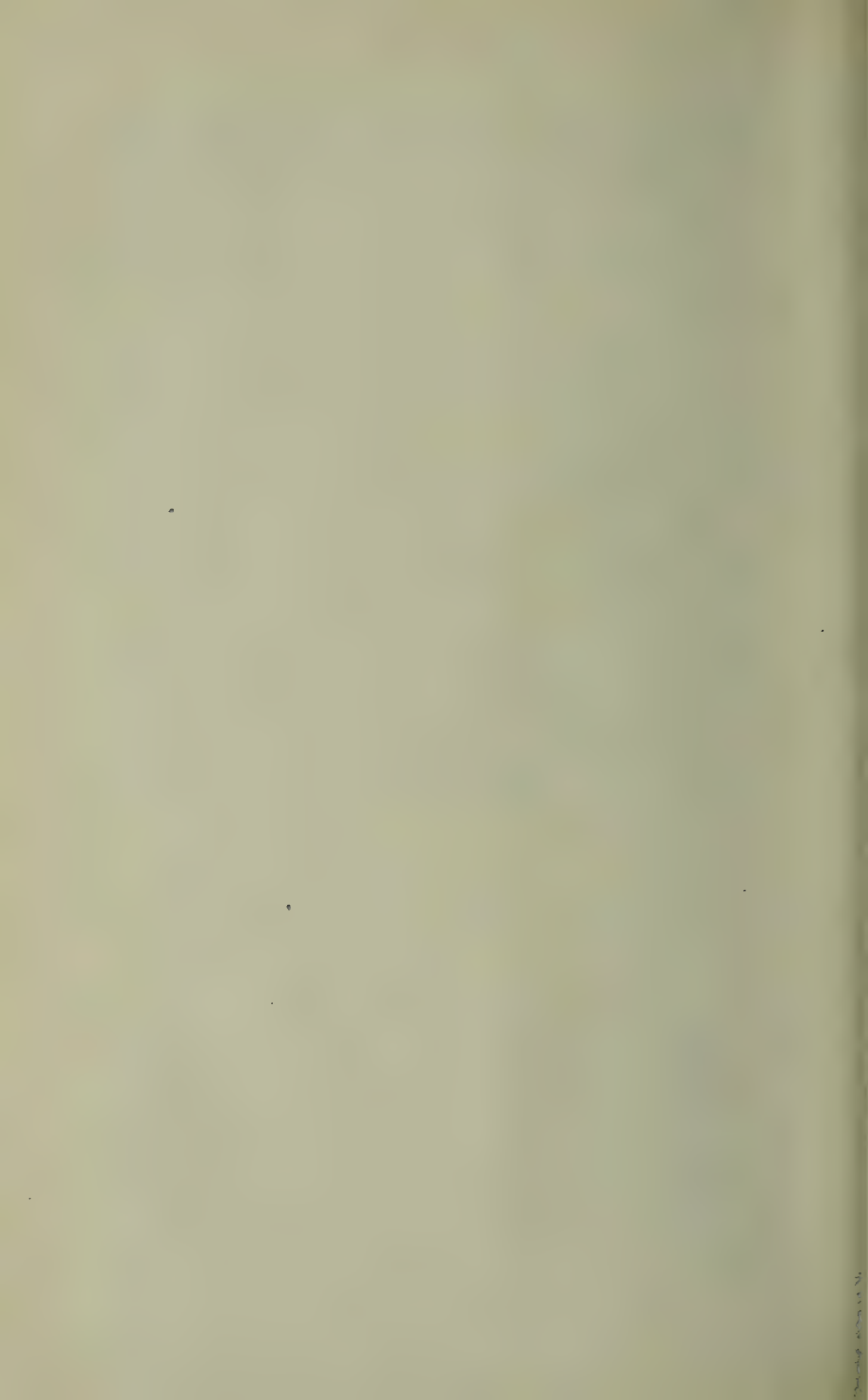
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SECTION III.

MEMORANDUM AND ARTICLES OF ASSOCIATION, AND LIST OF MEMBERS.

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The Companies (Consolidation) Act, 1908

Memorandum of Association

OF

THE INSTITUTE OF METALS

1. The name of the Company is THE INSTITUTE OF METALS.
2. The Registered Office of the Association will be situate in England.
3. The objects for which the Association is established are :—
 - (a) To take over the whole or any of the property and assets, which can be legally vested in the Association, and the liabilities and obligations of the unincorporated Society known as the Institute of Metals, and, with a view thereto, to enter into and carry into effect, with or without modifications, the agreement which has already been engrossed and is expressed to be made between Gilbert Shaw Scott of the one part, and the Association of the other part, a copy whereof has, for the purpose of identification, been signed by three of the subscribers hereto.
 - (b) To promote the science and practice of non-ferrous metallurgy in all its branches, and to assist the progress of inventions likely to be useful to the members of the Association and to the community at large.
 - (c) To afford a means of communication between members of the non-ferrous metal trades upon

matters bearing upon their respective manufactures other than questions connected with wages, management of works, and trade regulations.

- (d) To facilitate the exchange of ideas between members of the Association and between members of the Association and the community at large by holding meetings and by the publication of literature, and in particular by the publication of a Journal dealing wholly or in part with the objects of the Association.
- (e) To establish Branches of the Association either in the United Kingdom or abroad to be affiliated to the Association upon such terms and conditions as may be deemed advisable, but so that all such Branches shall prohibit the distribution of their income and property by way of dividend or otherwise amongst their members to an extent at least as great as is imposed on the Association by virtue of Clause 4 hereof.
- (f) To acquire by purchase, taking on lease or otherwise, lands and buildings and all other property real and personal which the Association, for the purposes thereof, may from time to time think proper to acquire and which may lawfully be held by them, and to re-sell, under-lease, or sublet, surrender, turn to account, or dispose of such property or any part thereof, and to erect upon any such land any building for the purposes of the Association, and to alter or add to any building erected upon such land.
- (g) To invest and deal with the moneys of the Association not immediately required in such manner as may from time to time be determined.
- (h) To borrow or raise or secure the payment of money in such manner as the Association shall think fit, and in particular by Mortgage or Charge upon

any of the property of the Association (both present and future), and to redeem and pay off any such securities.

- (i) To undertake and execute any trusts, the undertaking whereof may seem desirable.
- (k) To establish and support, or aid in the establishment and support of associations, institutions, funds, trusts, and conveniences calculated to benefit employees or ex-employees of the Association or the dependents or connections of such persons, and to grant pensions and allowances and to make payments towards insurances, and to subscribe or guarantee money for charitable or benevolent objects or for any Exhibition or for any public, general, or useful object.
- (l) To establish, form, and maintain a library and collection of metals, alloys, models, designs, and drawings, and other articles of interest in connection with the objects of the Association, or any of them.
- (m) To give prizes or medals as rewards for research, for inventions of a specified character, or for improvements in the production or manufacture of non-ferrous metals and their alloys, and to expend money in researches and experiments, and in such other ways as may extend the knowledge of non-ferrous metals and their alloys.
- (n) To do all things incidental or conducive to the attainment of the above objects or any of them.

Provided that the Association shall not support with its funds or endeavour to impose on or procure to be observed by its members any regulations which, if an object of the Association, would make it a Trade Union.

Provided also that in case the Association shall take or hold any property subject to the jurisdiction of the Charity Com-

missioners or Board of Education for England and Wales, the Association shall not sell, mortgage, charge, or lease the same without such authority, approval or consent as may be required by law, and as regards any such property the Council or Trustees of the Association shall be chargeable for such property as may come into their hands, and shall be answerable and accountable for their own acts, receipts, neglects, and defaults, and for the due administration of such property in the same manner and to the same extent as they would as such Council or as Trustees of the property of the Association have been if no incorporation had been effected, and the incorporation of the Association shall not diminish or impair any control or authority exercisable by the Chancery Division, the Charity Commissioners, or the Board of Education over such Council or Trustees, but they shall, as regards any such property, be subject jointly and separately to such control and authority as if the Association were not incorporated. In case the Association shall take or hold any property which may be subject to any trusts, the Association shall only deal with the same in such manner as allowed by law having regard to such trusts.

4. The income and property of the Association whencesoever derived shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly by way of dividend, bonus, or otherwise howsoever by way of profit, to the members of the Association. Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any member of the Association, in return for any services actually rendered to the Association, but so that no member of the Council or governing body of the Association shall be appointed to any salaried office of the Association or any office of the Association paid by fees, and that no remuneration or other benefit in money or money's worth shall be given to any member of such Council or governing body except repayment of out of pocket expenses and interest at a rate not exceeding 5 per cent. per annum on money lent, or reasonable and proper rent for premises demised to the Associa-

tion. Provided that this provision shall not apply to any payment to any railway, gas, electric lighting, water, cable, or telephone company of which a member of the Council or governing body may be a member, or any other company in which such member shall not hold more than one-hundredth part of the capital, and such member shall not be bound to account for any share of profits he may receive in respect of such payment.

5. The fourth paragraph of this Memorandum is a condition on which a license is granted by the Board of Trade to the Association in pursuance of Section 20 of the Companies (Consolidation) Act, 1908.

6. The liability of the members is limited.

7. Every member of the Association undertakes to contribute to the assets of the Association in the event of the same being wound up during the time that he is a member, or within one year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a member, and of the costs, charges and expenses of winding up the same, and for the adjustment of the rights of the contributories amongst themselves such amount as may be required not exceeding one pound.

8. If upon the winding-up or dissolution of the Association there remains, after satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the members of the Association, but shall be given or transferred to some other Institution or Institutions not formed or carrying on business for profit having objects similar to the objects of the Association, to be determined by the members of the Association at or before the time of dissolution, or in default thereof by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter, and if and so far as effect cannot be given to the aforesaid provision, then to some charitable objects.

9. True accounts shall be kept of the sums of money received and expended by the Association, and the matter in respect of which such receipt and expenditure takes place, and of the

property, credits, and liabilities of the Association, and, subject to any reasonable restrictions as to the time and manner of inspecting the same that may be imposed in accordance with the regulations of the Association for the time being, shall be open to the inspection of the members. Once at least in every year the accounts of the Association shall be examined and the correctness of the balance-sheet ascertained by one or more properly qualified auditor or auditors.

WE, the several persons whose names and addresses are subscribed, are desirous of being formed into an Association in pursuance of this Memorandum of Association.

NAMES, ADDRESSES, AND DESCRIPTIONS OF SUBSCRIBERS

GERARD ALBERT MUNTZ, French Walls, Birmingham, Baronet.

THOMAS TURNER, The University of Birmingham, Professor of Metallurgy.

ALFRED KIRBY HUNTINGTON, The University of London, Professor of Metallurgy.

WILLIAM H. JOHNSON, 24 Lever Street, Manchester, Iron Merchant and Manufacturer.

JAMES TAYLER MILTON, Lloyd's Register, E.C., Chief Engineer Surveyor.

ROBERT KAYE GRAY, Abbey Wood, Kent, Civil Engineer.

EMMANUEL RISTORI, 54 Parliament Street, London, S.W., Civil Engineer.

CECIL HENRY WILSON, Pitsmoor Road, Sheffield, Gold and Silver Refiner.

WILLIAM HENRY WHITE, 8 Victoria Street, Westminster, Naval Architect.

HENRY JOHN ORAM, Admiralty, London, S.W., Engineer Vice-Admiral.

Dated this 27th Day of July 1910.

Witness to the above signatures—

ARTHUR E. BURTON, Solicitor,
Hastings House, Norfolk Street,
Strand, W.C.

The Companies (Consolidation) Act, 1908

Articles of Association

OF

THE INSTITUTE OF METALS

SECTION I.—CONSTITUTION

1. For the purposes of registration the number of members of the Association is to be taken to be 1000, but the Council may from time to time register an increase of members.

2. The subscribers to the Memorandum of Association and such other members as shall be admitted in accordance with these Articles, and none others, shall be members of the Association and shall be entered on the register of members accordingly.

3. Every person who was a member of the unincorporated Society known as the Institute of Metals on the day preceding the date of the incorporation of this Association, and who has not already become a member of this Association by virtue of having subscribed the Memorandum of Association thereof, shall be entitled to be admitted to membership of the Association upon writing his name in a book which has been provided for that purpose, or upon notifying in writing to the Association at its Registered Office his desire to become a member, and immediately upon the making of such entry or the receipt of such notice, shall be deemed to have been admitted and to have become a member of the Association and shall be placed upon the register of members accordingly, and thereupon any sums due and owing by such persons to the unincorporated Society shall immediately become due and payable by him to the Association,

4. Members of the Association shall be either Honorary Members, Fellows, Ordinary Members, or Student Members, and shall be respectively entitled to use the following abbreviated distinctive titles: Hon. Members, Hon. M.Inst.Met.; Fellows, F.Inst.Met.; Ordinary Members, M.Inst.Met.; and Students, S.Inst.Met.

5. *Honorary Members.*—It shall be within the province of the Council to elect not more than twelve honorary members, who shall be persons of distinction interested in or connected with the objects of the Association. Honorary Members shall not be eligible for election on the Council nor entitled to vote at meetings of the Association, and the provisions of Article 7 and Clause 7 of the Memorandum of Association shall not apply to such members.

Fellows shall be chosen by the Council, shall be limited in number to twelve, and shall be members of the Institute who have, in the opinion of the Council, rendered eminent service to the Association.

Ordinary Members shall be more than twenty-three years of age, and shall be persons occupying responsible positions. They shall be either (a) persons engaged in the manufacture, working, or use of non-ferrous metals and alloys; or (b) persons of scientific, technical, or literary attainments connected with or interested in the metal trades or with the application of non-ferrous metals and alloys.

Student Members shall be more than seventeen years of age, and shall not remain Student Members of the Association after they are twenty-five years of age, and shall be either (a) Students of Metallurgy; or (b) pupils or assistants of persons qualified for ordinary membership whether such persons are actually members of the Association or not. Student Members shall not be eligible for election on the Council nor entitled to vote at the meetings of the Association.

SECTION II.—ELECTION OF MEMBERS

6. Save as hereinbefore provided, applications for membership shall be in writing in the Form following marked "A,"

and such application must be signed by the applicant and not less than three members of the Association.

FORM A.

To the Secretary.

I, the undersigned, _____, being of the required age and desirous of becoming a _____ Member of the Institute of Metals, agree that I will be governed by the regulations of the Association as they are now formed, or as they may be hereafter altered, and that I will advance the interests of the Association as far as may be in my power ; and we, the undersigned, from our personal knowledge, do hereby recommend him for election.

Name in full.....

Address.....

Business or Profession.....

Qualifications.....

Signature.....

Dated this _____ day of _____, 19 .

..... }
 } Signatures
 } of three
 } Members.

7. Such applications for membership as Ordinary Members or Student Members as are approved by the Council shall be inserted in voting lists. These voting lists will constitute the ballot papers, and will specify the name, occupation, address, and proposers of each candidate. They shall be forwarded to the members for return to the Secretary at a fixed date, and four-fifths of the votes recorded shall be necessary for the election of any person.

Every such election shall be subject to the payment by the applicant of his entrance fee and first annual subscription, and he shall not become a member of the Association nor be entered on the Register of Members until such sums are actually

received from him. In the event of his failing to pay such sums within the time specified in the notification to him of his election, as provided in the next clause hereof, his election shall be void.

8. Upon election under the preceding Article the Secretary shall forward to the applicant so elected notice thereof in writing in the Form marked "B."

FORM B.

SIR,—I beg to inform you that on the _____ you were elected a _____ Member of the Institute of Metals, subject to the payment by you of an entrance fee of £ _____, and of your first annual subscription of £ _____. These must be paid to me on or before the _____ day of _____ 19 _____, otherwise your election will become void.

I am, Sir, your obedient Servant,

.....Secretary.

9. In the case of non-election, no mention thereof shall be made in the minutes.

SECTION III.—COUNCIL AND MODE OF ELECTION

10. The affairs of the Association shall be managed and conducted by a Council, which shall consist of a President, Past-Presidents, six Vice-Presidents, fifteen Members of Council, an Hon. Secretary or Hon. Secretaries, and an Hon. Treasurer. All members who have filled the office of President shall be, so long as they remain members of the Association, *ex officio* additional members of the Council under the title of Past-Presidents. The first members of the Council shall be the following: *President*.—Sir Gerard Muntz, Bart.; *Vice-Presidents*.—Prof. H. C. H. Carpenter, Prof. W. Gowland, Prof. A. K. Huntington, Engineer Vice-Admiral H. J. Oram, Sir Henry A. Wiggin, Bart. *Ordinary Members of Council*.—T. A. Bayliss, G. A. Boeddicker, Clive Cookson, J. Corfield, R. Kaye Gray, Summers Hunter, Dr. R. S. Hutton, E. Mills, J. T. Milton, G. H. Nisbett, E. Ristori, A. E. Seaton, Cecil H. Wilson, Prof. T. Turner (Hon. Treasurer), W. H. Johnson (Hon. Secretary).

11. Clauses 87, 89, 91, 92, 93, and 94 of the Table A in the First Schedule of the Companies (Consolidation) Act, 1908, shall apply to and form part of the Regulations of the Association, with the substitution of "Members of the Council" for "Directors" wherever in such clauses occurring.

12. The quorum for the transaction of business by the Council may be fixed by the Council, but shall not be less than five.

13. The first business of the Association shall be to acquire the property and assets, and to undertake the liabilities and obligations of the unincorporated Society known as the Institute of Metals, and for the purpose of so doing the Council shall forthwith take into consideration, and, if approved, adopt on behalf of the Association, the Agreement referred to in Clause 3 (a) of the Memorandum of Association.

14. The President shall be elected annually, and shall be eligible for re-election at the end of the first year, but shall not be eligible for re-election again until after an interval of at least two years.

15. Two Vice-Presidents and five Members of the Council, in rotation, shall retire annually, but shall be eligible for re-election. The members of the Council to retire in every year shall be those who have been longest in office since their last election, but as between persons who became members of the Council on the same day, those to retire shall (unless they otherwise agree among themselves) be determined by lot. In addition, those Vice-Presidents and Members of Council shall retire who have not attended any meeting of the Council or Association during the previous year, unless such non-attendance has been caused by special circumstances which shall have been duly notified to, and accepted by, the Council as sufficient explanation of absence.

16. At the Ordinary General Meeting preceding the Annual Meeting, the Council shall present a list of members nominated by them for election on the Council. Any ten members may also, at such Meeting, nominate a candidate other than one of those nominated by the Council. A list of candidates so

nominated shall be forwarded to each member of the Association, and must be returned by him to be received by the Secretary not later than seven days preceding the Annual Meeting.

17. A member may erase any name or names from the list so forwarded, but the number of names on the list, after such erasure, must not exceed the number to be elected to the respective offices as before enumerated. The lists which do not accord with these directions shall be rejected by the Scrutineers. The votes recorded for any member as President, shall, if he be not elected as such, count for him as Vice-President, and, if not elected as Vice-President, shall count for him as ordinary member of the Council. And the votes recorded for any member as Vice-President shall, if he be not elected as such, count for him as ordinary member of the Council.

18. The Council shall have power to appoint a member to fill up any vacancy that may occur in the Council during their year of office, but any person so appointed shall hold office only until the next following Ordinary General Meeting, and shall then be eligible for re-election.

SECTION IV.—DUTIES OF OFFICERS

19. The President shall be Chairman at all Meetings at which he shall be present, and in his absence one of the Vice-Presidents, to be elected, in case there shall be more than one present, by the Meeting. In the absence of a Vice-President, the members shall elect a Chairman for that Meeting.

20. An account shall be opened in the name of the Association with a Bank approved by the Council, into which all moneys belonging to or received by the Association shall be paid. All cheques on such account shall be signed by a member of the Council and countersigned by the Honorary Treasurer. No account shall be paid before it has been certified as correct by the Council.

21. The Hon. Secretary or Secretaries shall be elected or appointed by the Council. He or they shall attend all Meetings,

shall take minutes of the proceedings, shall be responsible for the safe custody of all papers, books, and other moveable property of the Association, and shall perform such other duties as may be prescribed by the Council from time to time. In particular, he or they shall be responsible for editing the *Journal of the Institute of Metals*.

The Council shall have power to appoint a paid Secretary or Secretaries and to delegate to him or them all or any of the duties of the Hon. Secretary or Secretaries.

SECTION V.—GENERAL MEETINGS

22. The First General Meeting shall be held at such time, not being more than three months after the incorporation of the Association, and at such place as the Association may determine. Subsequent there shall be at least two General Meetings in each calendar year, one of which shall be held in London during the first three months of the calendar year, and the other at such time after the said Meeting to be held in London and in such locality as the Council may direct. The Meeting in London shall be the Annual General Meeting.

The quorum for a General Meeting shall be ten members personally present.

23. The Council may convene an Extraordinary General Meeting for any special purpose whenever they consider it to be necessary. The Council shall convene an Extraordinary General Meeting for a special purpose, upon a requisition to that effect, signed by not less than twenty members. The business of such a Meeting shall be confined to the special subjects named in the notice convening the same. No member whose subscription is in arrear shall be entitled to debate or to vote at any General Meeting.

In case of equality of voting at any Meeting the Chairman shall have an additional or casting vote.

24. Seven days' notice at the least (exclusive of the day on

which the notice is served or deemed to be served, but inclusive of the day for which notice is given) specifying the place, the day, and the hour of Meeting, and, in case of special business, the general nature of that business, shall be given in manner hereinafter mentioned, or in such other manner, if any, as may be prescribed by the members of the Association in General Meeting, to such persons as are, under the regulations of the Association, entitled to receive such notices from the Association, but the non-receipt of the notice by any member shall not invalidate the meeting.

25. A notice may be given by the Association to any member, either personally or by sending it by post to him to his registered address, or (if he has no registered address in the United Kingdom) to the address, if any, within the United Kingdom supplied by him to the Association for the giving of notices to him.

Where a notice is sent by post, service of the notice shall be deemed to be effected by properly addressing, prepaying, and posting a letter containing the notice, and a certificate of the Secretary or other Officer of the Association that such notice was so posted shall be sufficient proof of service. A notice so posted shall be deemed to have been served the day following that upon which it was posted.

26. If a member has no registered address in the United Kingdom, and has not supplied to the Association an address within the United Kingdom for the giving of notices to him, a notice addressed to him and advertised in a newspaper circulating in the neighbourhood of the registered office of the Association shall be deemed to be duly given to him on the day on which the advertisement appears.

27. Notice of every General Meeting shall be given in some manner hereinbefore authorised to every member of the Association, except those members who (having no registered address within the United Kingdom) have not supplied to the Association an address within the United Kingdom for the giving of notices to them. No other persons shall be entitled to receive notices of General Meetings, but the Association may, but shall not be

bound to give notice of General Meetings to members not entitled thereto in such manner as in the opinion of the Council may be practicable and convenient.

SECTION VI.—SUBSCRIPTIONS

28. The subscription of each Ordinary Member shall be two guineas per annum, and of each Student Member one guinea per annum. Ordinary Members shall pay an entrance fee of two guineas each, and Students an entrance fee of one guinea each. Provided that no entrance fee shall be required from any person who was a member of the unincorporated Society known as the Institute of Metals on the day preceding the Incorporation of this Association, and who had paid an entrance fee to the said Society. No entrance fee or subscription shall be payable in the case of Honorary Members.

29. Subscriptions shall be payable in advance on July 1st in each year, save in the case of Ordinary Members and Student Members elected under Clauses 6 and 7 hereof, whose entrance fee and annual subscription shall become payable in accordance with the notification to them of their election. Every subscription shall cover the period down to the 30th of June next following, and no longer, and for this purpose any subscription paid to the unincorporated Society for the period of July 1st, 1909, to June 30th, 1910, by any person who becomes a member of this Association shall go and be in satisfaction of any payment due in respect of membership of this Association up to the 30th of June 1910.

30. Subject to the provisions of Clause 7 hereof, any member whose subscription shall be six months in arrear, shall forfeit temporarily all the privileges of the Association. Due notice in the Form following marked "C" shall be given to such member, and if such subscription remains unpaid upon the date specified for payment in this notice, the Council may remove such member from the Register of Members of the Association, and thereupon any member whose name is so removed shall cease to be a member thereof, but shall nevertheless remain liable to the Association for such arrears.

FORM C.

SIR,—I am directed to inform you that your subscription to the Institute of Metals, due _____, and amounting to £ _____, is in arrear, and that if the same be not paid to me on or before the _____ day of _____, 19____, your name will be removed from the Register of Members of the Association.

I am, Sir, your obedient Servant,

.....Secretary.

31. The Council may, in their discretion, and upon such terms as they think fit (including the payment of all arrears), accede to any application for reinstatement by a person whose name has been removed from the Register under the last preceding Clause hereof, and the name of any person so reinstated shall be placed upon the Register of Members accordingly.

The Council, in their discretion, may remove from the Register the name of any member who shall, in the opinion of the Council, be undesirable or unfit to remain a member after first giving him a reasonable opportunity of being heard, and thereupon he shall cease to be a member of the Association.

SECTION VII.—AUDIT

32. The provisions of the Companies (Consolidation) Act, 1908, as to Audit and Auditors shall apply to and be observed by the Association, the first General Meeting being treated as the Statutory Meeting, the Council being treated as the Directors, and the members being treated as the Shareholders mentioned in that Act.

SECTION VIII.—JOURNAL

33. The Journal of the Association may include one or more of the following :—

- (a) Communications made by members, students, or others.
- (b) Abstracts of papers appearing elsewhere.
- (c) Original papers appearing elsewhere.
- (d) Advertisements approved by the Council.

Every member shall be entitled to receive one copy of each issue of the Journal, delivered, post free, to his registered address.

SECTION IX.—COMMUNICATIONS

34. All communications should be submitted to the Council, and those approved may be brought before the General Meetings. This approval by the Council shall not be taken as expressing an opinion on the statements made or the arguments used in such communications.

SECTION X.—PROPERTY OF THE ASSOCIATION

35. All communications so made shall be the property of the Association, and shall be published only in the Journal of the Association, or in such other manner as the Council may decide.

36. All books, drawings, communications, models, and the like shall be accessible to members of the Association, and the Council shall have power to deposit the same in such place or places as they may consider convenient for the members.

SECTION XI.—CONSULTING OFFICERS

37. The Council shall have power to appoint such consulting officers as may be thought desirable from time to time, and, subject to the provisions of Clause 4 of the Memorandum of Association, may vote them suitable remuneration.

SECTION XII.—INDEMNITY

38. Every Member of Council, Secretary, or other officer or servant of the Association, shall be indemnified by the Association against, and it shall be the duty of the Council out of the funds of the Association to pay all costs, losses, and expenses which any such officer or servant may incur or become liable to by reason of any contract entered into or act or thing done by him as such officer or servant or in any way in the discharge of his duties, including travelling expenses.

NAMES, ADDRESSES, AND DESCRIPTIONS OF SUBSCRIBERS

GERARD ALBERT MUNTZ, French Walls, Birmingham, Baronet.

THOMAS TURNER, The University of Birmingham, Professor of Metallurgy.

ALFRED KIRBY HUNTINGTON, The University of London, Professor of Metallurgy.

WILLIAM H. JOHNSON, 24 Lever Street, Manchester, Iron Merchant and Manufacturer.

JAMES TAYLER MILTON, Lloyd's Register, E.C., Chief Engineer Surveyor.

ROBERT KAYE GRAY, Abbey Wood, Kent, Civil Engineer.

EMMANUEL RISTORI, 54 Parliament Street, London, S.W., Civil Engineer.

CECIL HENRY WILSON, Pitsmoor Road, Sheffield, Gold and Silver Refiner.

WILLIAM HENRY WHITE, 8 Victoria Street, Westminster, Naval Architect.

HENRY JOHN ORAM, Admiralty, London, S.W., Engineer Vice-Admiral.

Dated this 27th Day of July 1910.

Witness to the above signatures—

ARTHUR E. BURTON, Solicitor,

Hastings House, Norfolk Street,
Strand, W.C.

LIST OF MEMBERS

Members of Council are indicated by italics.

Original Members are those who were elected 1908-9.

† *Denotes Contributor of Paper.*

* *Denotes Corresponding Member to the Council.*

HONORARY MEMBERS

Elected
Member.

- | | |
|------|---|
| 1916 | CROOKES, Professor Sir WILLIAM, Kt., O.M., Past-Pres. R.S.,
LL.D.,
7 Kensington Park Gardens, W. |
| 1910 | GLAZEBROOK, RICHARD TETLEY, C.B., M.A. (Cantab.),
Sc.D., F.R.S.,
Director, The National Physical Laboratory, Teddington, Middlesex. |
| 1912 | LE CHATELIER, Professor HENRY,
75 Rue Notre Dame des Champs, Paris, France. |
| 1916 | THOMSON, Sir JOSEPH JOHN, Kt., O.M., D.Sc., F.R.S.,
"Holmleigh," West Road, Cambridge. |

ORDINARY MEMBERS

- | | |
|--------|--|
| 1911 | ABBOTT, ROBERT ROWELL, B.Sc.,
Peerless Motor Car Co., Cleveland, O., U.S.A. |
| 1915 | ABELL, WESTCOTT STILE, M.Eng.,
Lloyd's Register of British and Foreign Shipping,
71 Fenchurch Street, E.C. |
| 1908-9 | ADAMS, GEORGE,
Strathblane, Forest Glade, Leytonstone, Essex. |
| 1908-9 | ADAMSON, JOSEPH,
Oaklands, Hyde, Cheshire. |
| 1908-9 | AINSWORTH, GEORGE,
The Hall, Consett, Durham. |

Elected
Member.

- 1910 ALLAN, ANDREW, Junr.,
A. Allan & Son, 486 Greenwich Street, New York,
U.S.A.
- 1908-9 ALLAN, JAMES MCNEAL,
Cammell, Laird & Company, Limited, Cyclops Works,
Sheffield.
- 1908-9 ALLELY, WILLIAM SMITH,
3 Regent Street, Birmingham.
- 1908-9 ALLEN, JOHN HILL,
54 Westfield Road, Edgbaston, Birmingham.
- 1912 ALLEN, THOMAS JAMES WIGLEY,
German Silver Works, Spring Hill, Birmingham.
- 1908-9 ALLEN, WILLIAM HENRY,
*W. H. Allen, Son & Company, Limited, Queen's
Engineering Works, Bedford.*
- 1910 ALMOND, GEORGE,
Nemaha City, Nemaha County, Nebraska, U.S.A.
- 1908-9 † ANDREW, JOHN HAROLD, D.Sc.,
Sir W. G. Armstrong, Whitworth & Company, Limited,
Ashton Road, Openshaw, Manchester.
- 1916 ANDREWS, JOSEPH C.,
123 Vine Street, New Britain, Conn., U.S.A.
- 1910 ANDRI, ALFRED,
General Manager, Fabrique Nationale d'Armes de
Guerre, Herstal-près-Liége, Belgium.
- 1908-9 APPLETON, JOSEPH,
Appleton & Howard, 12 Salisbury Street, St. Helens.
- 1908-9 ARCHBUTT, LEONARD,
4 Madeley Street, Derby.
- 1915 ARKWRIGHT, WILFRID LIONEL TYRELL,
Duram, Limited, Caxton House, Westminster, S.W.
- 1914 ARNOTT, JOHN,
Laboratory Department, G. & J. Weir, Limited,
Cathcart, Glasgow.
- 1910 ASH, Engineer-Commander HAROLD EDWARD HAYDON, R.N.,
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- 1916 AUBIÉ, PROSPER PIERRE,
"L'Aluminium Français," Usine de Chambéry (Savoie),
France.
- 1915 AUTY, CLIFFORD MARSHALL, B.Sc.,
37 Shakespeare Street, Ardwick, Manchester.
- 1914 AYERS, Engineer-Capt. ROBERT BELL, M.V.O., R.N. (Rtd.),
15 Infield Park, Barrow-in-Furness.
- 1908-9 † BAILEY, GEORGE HERBERT, D.Sc., Ph.D.,
Edenmor, Kinlochleven, Argyll, N.B.
- 1908-9 BAIN, JAMES,
The Cunard Engine Works, Huskisson Docks, Liverpool.
- 1908-9 BAKER, THOMAS, D.Sc., M.Met.,
"Westville," Doncaster Road, Rotherham, Yorks.
- 1908-9 BAMFORD, CHARLES CLIFFORD,
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60 West Side, Clapham Common, S.W.
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31 Glenalmond Road, Ecclesall, Sheffield.
- 1908-9 BARKER, JOHN HENRY,
"San Simeon," Newbridge Crescent, Wolverhampton.
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H. B. Barnard & Sons, 148½ Fenchurch St., E.C.
- 1908-9 BARNARD, GEORGE,
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- 1908-9 BARR, Professor ARCHIBALD, D.Sc. (Glas.),
Westerton, Milngavie, N.B.
- 1908-9 BARWELL, CHARLES H.,
Barwells Ltd., Pickford Street, Birmingham.
- 1910 BASSETT, WILLIAM H.,
American Brass Co., Waterbury, Conn., U.S.A.
- 1908-9 BAWDEN, FREDERICK,
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- 1916 BAXTER, CHARLES,
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- 1915 BAXTER, PETER MACLEOD,
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- 1914 BEARDMORE, SIR WILLIAM, Bart.,
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(Lond.),
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H. H. Vivian & Co., Ltd., Icknield Port Road,
Birmingham.
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137 Lapwing Lane, Didsbury, Manchester.
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Chemical Laboratory, Michael Artillery Academy,
Petrograd, Russia.
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- 1908-9 BELL, THOMAS,
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Tegnér lunden 3^{iv}, Stockholm Va, Sweden.
- 1908-9 † BENGOUGH, GUY DUNSTAN, M.A. (Cantab.), D.Sc. (Liv.),
Royal School of Mines, South Kensington, S.W.
- 1908-9 BEVIS, HENRY,
Pirelli, Limited, 144 Queen Victoria Street, E.C.
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John Bibby & Company (Garston), Limited, Garston
Copper Works, Liverpool.
- 1908-9 BILL-GOZZARD, GEORGE,
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on-Trent.
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- 1908-9 BRABY, CYRUS,
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1 Cannon Street, Birmingham.
- 1910 BROOK, GEORGE BERNARD,
Non-ferrous Metallurgical Department, The University,
St. George's Square, Sheffield.
- 1913 BROTHERHOOD, STANLEY,
Peterborough.
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"Glenroy," Gillott Road, Edgbaston, Birmingham.
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Scotts' Shipbuilding and Engineering Company,
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David Brown & Sons (Huddfd.) Limited, Huddersfield.
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109 Oxford Road, Moseley, Birmingham.
- 1908-9 † BRÜHL, PAUL THEODOR, M.Sc.,
Aurora Consolidated Mines Company, Aurora, Nevada,
U.S.A.
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Stanground House, Peterborough.
- 1914 BUCK, HENRY ARTHUR,
London Metal Exchange, Whittington Avenue, E.C.
- 1908-9 BUCKWELL, GEORGE WILLIAM,
Board of Trade Surveyors' Office, 73 Robertson Street,
Glasgow.
- 1908-9 BULLEID, Professor CHARLES HENRY, M.A.,
University College, Nottingham.
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- 1915 CAMPBELL, HUGH,
"Newshead," Halifax, Yorkshire.
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W. Canning & Co., 133 Great Hampton Street,
Birmingham.
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General Electric Company, Schenectady, N.Y., U.S.A.
- 1912 CARDOZO, HENRI ALEXANDRE,
54 Rue de Prony, Paris, France.
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53 Dock, Ghent, Belgium.
- 1913 CARNT, Engineer-Commander ALBERT JOHN, R.N. (Rtd.),
"St. Bedes," Walton, Peterborough.
- 1908-9 † CARPENTER, Professor HENRY CORT HAROLD, M.A.
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Royal School of Mines, South Kensington, S.W.
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Foundry, Smethwick, Birmingham.
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The Admiralty, Whitehall, Westminster, S.W.
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"Rhoslwyn," Plastirion Avenue, Prestatyn, North
Wales.
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Cammell, Laird & Company, Limited, Birkenhead.
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- 1916 CHILD, WALTER HAYDN,
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The Ajax Metal Company, Frankford Avenue,
Philadelphia, Pa., U.S.A.
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George Clark, Limited, Southwick Engine Works,
Sunderland.
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British India Steam Navigation Company, Limited,
9 Throgmorton Avenue, E.C.
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"Newnham," Holly Lane, Erdington, Birmingham.
- 1913 CLARK, WILLIAM WALLACE, Ph.D.,
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Thermit, Limited, 675 Commercial Road, Limehouse, E.
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Redvers House, Hillaries Road, Gravelly Hill,
Birmingham.
- 1914 CLARKE, WALTER G.,
46 Foxbourne Road, Balham, S.W.
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14 Hatfield Drive, Kelvinside, Glasgow.
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Sheffield Testing Works, Blonk Street, Sheffield.
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- 1908-9 COE, HARRY IVOR, M.Sc.,
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van't Hoff Laboratory, The University, Utrecht,
Holland.
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Brooklands, Osgathorpe, Sheffield.
- 1909 CONNOLLY, JAMES,
Zuurfontein Foundry, Zuurfontein, Transvaai, South
Africa.
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Cookson & Company, Limited, Milburn House, New-
castle-on-Tyne.
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- 1908-9 CORSE, WILLIAM MALCOLM, B.Sc.,
Secretary, American Institute of Metals, 106 Morris
Avenue, Buffalo, N.Y., U.S.A.
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"The Cottage," French Street, Sunbury-on-Thames.
- 1910 CRAWFORD, WILLIAM MITCHELL,
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Glasgow.
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Harland & Wolff, Limited, Bootle, Liverpool.
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Shubbery House, Bloomfield Road, Tipton.
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Milburn House, Newcastle-on-Tyne.
- 1908-9 CROSSLEY, PERCY BROADBENT,
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Road, S.W.
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Copper Mills, Garston, Liverpool.
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162 Rosendale Road, Dulwich, S.E.
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85 Teignmouth Road, Brondesbury, N.W.
- 1914 DAWSON, Sir ARTHUR TREVOR, Kt., R.N.,
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- 1910 DAWSON, WILLIAM FRANCIS,
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Metallurgical Chemistry Laboratory, The University,
Glasgow.
- 1914 DEWAR, JAMES MCKIE,
Cammell, Laird & Company, Limited, 3 Central
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36 Eaton Crescent, Swansea.
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Dugard Brothers, Shadwell Street Mills, Birmingham.
- 1911 DUNCAN, HUGH MALCOLM, B.Sc.,
5 King Edward's Road, Heaton, Newcastle-on-Tyne.
- 1908-9 DUNN, JOHN THOMAS, D.Sc. (Dun.),
Public Analyst's Laboratory, 10 Dean Street, New-
castle-on-Tyne.
- 1911 DUNSMUIR, GEORGE AUGUSTUS,
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50 Heavitree Road, Plumstead, S.E.
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- 1914 ELLIS, OWEN WILLIAM, B.Sc. (Birm.),
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H.M. Repair Depôt, Invergordon, Ross-shire, Scotland.
- 1914 ENGLISH, SOLOMON, M.Sc.,
The University, Sheffield.
- 1910 ENTHOVEN, HENRY JOHN,
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- 1913 ESPIR, FERNAND,
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Zetland Buildings, Middlesbrough, Yorks.
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6 Balm Road, Hunslet, Leeds.
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28 Victoria Street, Westminster, S.W.
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Evered & Company, Limited, Surrey Works, Smeth-
wick, Birmingham.
- 1916 FAHRENWALD, FRANK ALFRED, Ph.D., M.Sc., E.M.,
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Mass. Institute of Technology, Boston, Mass., U.S.A.
- 1908-9 FÉRON, ALBERT,
49 Rue du Châtelain, Brussels, Belgium.
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Bridgeport Brass Company, Bridgeport, Conn., U.S.A.
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- 1915 FISHWICK, ERNEST ARTHUR,
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- 1913 FITZ-BROWN, GEORGE, A.R.S.M.,
Ditton Copper Works, Widnes.
- 1915 FLACK, SIDNEY ERIC,
Bull's Metal and Melloid Company Limited, Yoker,
near Glasgow.
- 1911 FOERSTERLING, HANS,
The Roessler and Hasslacher Chemical Company,
Perth Amboy, N.J., U.S.A.
- 1911 FORSBERG, ERIK AUGUST,
Aktiebolaget Separator, Fleminggatan 8, Stockholm,
Sweden.
- 1910 FORSTEDT, JAMES,
Västerås, Sweden.
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- 1914 FRANK, WILLIAM KLEE,
Damascus Bronze Company, Pittsburg, Pa., U.S.A.
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The Yorkshire Copper Works, Limited, Pontefract
Road, Leeds.
- 1915 FRENCH, DOUGLAS GORDON, B.A. (Cantab.), B.Sc. (Lond),
Birmingham Metal and Munitions Company Limited,
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Sabalkanski 26 / 49, lg. 5, Petrograd, Russia.
- 1908-9 GARDNER, HENRY,
Stanstead Lodge, Forest Hill, S.E.
- 1908-9 GARDNER, JAMES ALEXANDER,
21 Cuthbert Place, Kilmarnock, Ayrshire.
- 1908-9 GARFIELD, ALEXANDER STANLEY, B.Sc.,
10 Rue de Londres, Paris, France.
- 1912 † * GARLAND, HERBERT,
P.O. Box 417, Cairo, Egypt.
- 1908-9 GARNHAM, FREDERICK MALCOLM,
"Brooklyn," 76b Amhurst Park, Stamford Hill, N.
- 1908-9 GARNHAM, JAMES COOTE,
132 Upper Thames Street, E.C.
- 1912 GARRETT-SMITH, NOEL,
"Heathside," Treville Street, Roehampton.
- 1908-9 GAYWOOD, CHARLES FREDERICK,
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- 1912 GEM, EVELYN PERCY,
George Johnson & Company, Montgomery Street,
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Alderley Edge, Manchester.
- 1911 GIBB, MAURICE SYLVESTER,
Central Marine Engine Works, West Hartlepool.
- 1908-9 GIBBINS, WILLIAM WATERHOUSE, M.A.,
Selly Oak, Birmingham.
- 1908-9 GIBBONS, WILLIAM GREGORY,
32 Victoria Street, Westminster, S.W.
- 1913 GIBBS, LEONARD,
"Abermaw," School Road, Hall Green, Birmingham.
- 1916 GIBSON, JOSEPH HAMILTON,
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- 1914 GILLIGAN, FRANK P.,
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15 Queen Anne's Mansions, S.W.
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The Birmingham Aluminium Casting (1903) Company, Limited, Cambridge Street, Birmingham.
- 1908-9 † GOWLAND, Professor WILLIAM, F.R.S., A.R.S.M. (Past-President),
13 Russell Road, Kensington, W.
- 1908-9 GRACIE, ALEXANDER, M.V.O.,
Fairfield Works, Govan, Glasgow.
- 1912 GRAHAM, ALFRED HENRY IRVINE,
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- 1908-9 GREENWOOD, THOMAS,
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- 1910 GREENWOOD, VLADIMIR EDWARD.
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- 1908-9 GREER, HENRY HOLME AIREY,
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5 Beach Mansions, Southsea, Hampshire.
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Gamble Institute, St. Helens, Lancashire.
- 1912 GUESS, Professor GEORGE A.,
Oakville, Ontario, Canada.
- 1908-9 GUILLEMIN, GEORGES,
16 Rue du Sommerard, Paris (5^e), France.
- 1908-9 GUILLET, Professor LÉON,
8 Avenue des Ternes, Paris, France.
- 1908-9 † GULLIVER, GILBERT HENRY, D.Sc.,
Testing and Experimenting Works, 99 Southwark
Street, S.E.
- 1908-9 GWYER, ALFRED GEORGE COOPER, B.Sc. (Lond.), Ph.D.
(Gott.),
Research Laboratory, The British Aluminium Company,
Limited, Warrington, Lancs.
- 1914 GWYNNE, NEVILL G.,
Gwynnes, Limited, Hammersmith Ironworks, W.
- 1910 HADDOCK, WALTER THORPE,
The Heeley Silver-Rolling and Wire Mills, Ltd.,
Sheffield.
- 1908-9 HADFIELD, Sir ROBERT ABBOTT, Kt., D.Sc., D.Met., F.R.S.,
22 Carlton House Terrace, S.W.
- 1916 HALL, GEORGE CLAVERING,
"Mayfield," London Road, Peterborough.
- 1908-9 HALL, HENRY PLATT,
Platt Brothers and Company, Limited, Oldham.
- 1916 HALL, JOHN PERCY, Junr., M.A.,
2 Redington Gardens, Hampstead, N.W.
- 1914 HAM, Engineer-Captain JOHN WILLIAM, R.N.,
28 Telford Avenue, Streatham Hill, S.W.
- 1908-9 HAMILTON, GERARD MONTAGUE,
16 Westmount Road, Eltham, Kent.
- 1911 HANKINSON, ALFRED,
Richard Johnson, Clapham & Morris, Limited, P.O.
Box 1102, Sydney, Australia.

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Robert Harlow & Son, Heaton Norris, Stockport.
- 1914 HARRIS, HENRY, A.R.S.M.,
Upper Ordnance Wharf, Rotherhithe, S.E.
- 1914 HARRIS, JONATHAN WISTAR, B.S.,
Western Electric Company, 463 West Street, New
York, N.Y., U.S.A.
- 1911 HARRISON, JOHN SAMUEL,
"Llanberis," Chester Road, near Erdington, Birming-
ham.
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Royal Laboratory, Royal Arsenal, Woolwich.
- 1916 HATFIELD, WILLIAM HERBERT, D.Met. (Shef.),
7 Victoria Road, Broomhall Park, Sheffield.
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The National Physical Laboratory, Teddington,
Middlesex.
- 1908-9 HEAP, JOHN HENRY,
The British Mining and Metal Company, Limited,
Greenhill Works, Gunnislake, Tavistock.
- 1908-9 HEAP, RAY DOUGLAS THEODORE,
12 Little College Street, Westminster, S.W.
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Rudge-Whitworth, Limited, Coventry.
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Birmingham Metal Works, Frederick Street, Birming-
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Street, Glasgow.
- 1908-9 HERDSMAN, WILLIAM HENRY,
144 Wellington Street, Glasgow.
- 1911 HEWITT, Professor JOHN THEODORE, M.A. (Cantab.),
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20 Graham Street, City Road, N.
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5 Windsor Crescent, Newcastle-on-Tyne.
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49 Union Street, Leigh, Lancashire.
- 1915 HJELMSÄTER, J. O. ROOS AF,
Testing Institute, Stockholm, Sweden.
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89 Shooter's Hill Road, Blackheath, S.E.
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Institute of Technology, Boston, Mass., U.S.A.
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near Newcastle-on-Tyne.
- 1908-9 HOLLOWAY, GEORGE THOMAS,
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Brondeg, Llanelly, South Wales.
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Broad Brook Road, Bedford Hills, N.Y., U.S.A.
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23 Plymouth Avenue, Manchester.
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Royal School of Mines, South Kensington, S.W.
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Albion Metal Works, Woodcock Street, Birmingham.
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American Brass Company, Kenosha, Wisconsin, U.S.A.
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- 1910 HUNTER, Engineer Lieutenant SUMMERS, R.N.,
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- 1916 ISHIKAWA, Engineer Lieutenant-Commander TOKIJI, I.J.N.,
Imperial Japanese Navy, Broadway Court, Broadway,
Westminster, S.W.
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46-47 Finsbury Square, E.C.
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- 1908-9 JACOBS, HARRY,
Exchange Buildings, New Street, Birmingham.
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- 1914 JAMESON, CHARLES GODFREY,
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leven, Argyllshire.
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Belliss & Morcom, Limited, Birmingham.
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Nikko Furnkawa Copper Works, Nikko, Japan.
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Warstone Metal Works, Hall Street, Birmingham.
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Broughton Copper Company, Limited, Manchester.
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- 1910 KIDSTON, WILLIAM HAMILTON,
81 Great Clyde Street, Glasgow.
- 1908-9 KING, ERNEST GERALD. Editor. *The Metal Industry*,
33 Bedford Street, Strand, W.C.
- 1915 KITAZAWA, TAKEO,
Yamato Metal Company, Kyobashi-ku, Tokyo, Japan.
- 1908-9 † KLEIN, CARL ADOLPHE,
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99 John Street, New York City, U.S.A.
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- 1916 LINDSAY, CHARLES FOWLER, Ph.D.,
Imperial Munitions Board, Transportation Building,
Ottawa, Canada.
- 1912 LITTLE, ARTHUR DEHON,
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Partick, Glasgow.
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Engineering Experiment Station, U.S.A., Naval Aca-
demy, Annapolis, Maryland, U.S.A.
- 1916 McCANCE, ANDREW, A.R.S.M., B.Sc.,
63 Lauderdale Gardens, Hyndland, Glasgow.
- 1908-9 McCONWELL, ARTHUR,
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Russia.

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- 1910 McKECHNIE, JAMES,
Vickers, Limited, Barrow-in-Furness.
- 1908-9 McLaurin, Engineer-Commander JOHN, R.N.,
The Laurels, Branksome Wood Road, Fleet,
Hampshire.
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Kalimati, B.N. Railway, India.
- 1912 MALBY, SETH GRANT,
Aluminium Company of America, 120 Broadway,
New York City, U.S.A.
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G. Thompson & Company, Limited, Aberdeen White-
Star Line, Billiter Square, E.C.
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Liverpool Street, Birmingham.
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J. Wilkes, Sons & Mapplebeck, Limited, Liverpool
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Yarrow & Company, Glasgow.
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H.M.S. *Monarch*, 2nd Battle Squadron, Home Fleet.
- 1910 MASON, FRANK,
Wayland House, 70 Wayland Road, Sheffield.
- 1910 MAW, WILLIAM HENRY, LL.D.,
18 Addison Road, Kensington, W.
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155 Dashwood House, New Broad Street, E.C.

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Laboratorio di Chimica Applicata, R. Università di
Padova, Padova, Italy.
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- 1908-9 MERRETT, WILLIAM HENRY, A.R.S.M.,
Hatherley, Grosvenor Road, Wallington, Surrey.
- 1914 METCALF, HENRY ERNEST,
Babcock & Wilcox, Limited, Oriel House, Farringdon
Street, E.C.
- 1908-9 MEYJES, ANTHONY CORNELIUS, Editor, *The Ironmonger*,
42 Cannon Street, E.C.
- 1910 MEYRICK, LEWIS JENKIN,
137 City Road, Birmingham.
- 1911 MICHIE, ARTHUR C., D.Sc.,
The Wallsend Laboratories, Neptune Road, Wallsend-
on-Tyne.
- 1908-9 MILLER, JOHN,
365 Potomac Avenue, Buffalo, N.Y., U.S.A.
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406 Orchard Street, Rochester, New York, U.S.A.
- 1908-9 MILLINGTON, ERNEST,
Manor Road, Borrowash, Derby.
- 1908-9 MILLS, EDWARD,
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Grice, Grice & Son, Limited, Nile Street, Birmingham.
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- 1915 MILLS, PERCY HERBERT,
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- 1908-9 MILLS, WILLIAM,
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- 1913 MORISON, Engineer-Commander RICHARD BARNES, R.N.
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- 1908-9 MORRISON, WILLIAM MURRAY,
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Woodhead Avenue, Kirkintilloch, Dumbartonshire.
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- 1914 MURRAY, CHARLES WALTER,
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- 1916 NORMAN, PHILIP WILLIAM,
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- 1914 NORTON, ALLEN BULLARD,
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- 1910 OAKDEN, WILLIAM EDWARD,
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Holeyn Hall, Wylam-on-Tyne.
- 1914 PARSONS, CHARLES FREDERICK,
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Wellington, Shropshire.
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- 1908-9 PATERSON, JOHN,
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Levenford Works, Dumbarton.
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Polytechnic Institute, Petrograd, Russia.
- 1908-9 PEARCE, RICHARD, Ph.D. (Columb.),
6 Beach Lawn, Waterloo, Liverpool.
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- 1908-9 † PHILIP, ARNOLD, B.Sc., A.R.S.M.,
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Portsmouth.*
- 1914 PIRRIE, The Rt. Hon. Lord, K.P., P.C.,
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- 1915 PLATTEN, FRANK,
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- 1912 PLAYER, WILLIAM,
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- 1915 PLENTY, EDWARD PELLEW,
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- 1908-9 QUIRK, JOHN STEBLE,
Quirk, Barton & Burns, St. Helens, Lancashire.
- 1908-9 RADLEY, WILLIAM ALBERT,
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- 1915 RAE, WILLIAM,
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- 1913 RAWORTH, BENJAMIN ALFRED, Wh.Sc.,
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INSTITUTE OF METALS.

Founded 1908.

Incorporated 1910.

To the Secretary,

I, the undersigned....., being of the required age and desirous of becoming a.....Member of the INSTITUTE OF METALS, agree that I will be governed by the regulations of the Association as they are now formed, or as they may be hereafter altered, and that I will advance the interests of the Association as far as may be in my power; and we, the undersigned, from our personal knowledge, do hereby recommend him for election.

Name in full.....

Address.....

Business or Profession.....

Qualifications.....

Signature.....

Dated this.....day of....., 191 .

.....) Signatures of three Members
.....	
.....	

The Council, having considered the above recommendation,
sent Mr.....to be Balloted for as a.....
mber of the INSTITUTE OF METALS.

To be filled up
by the
Council

CAXTON HOUSE,

WESTMINSTER, S.W.

Chairman.

Dated this.....day of.....191.....

FOR QUALIFICATIONS OF MEMBERS, SEE SECTION I, OTHER SIDE.

(It would be a convenience if the Candidate's Card were sent with this form.)

EXTRACTS FROM THE RULES.

(MEMORANDUM AND ARTICLES OF ASSOCIATION.)

SECTION I.—CONSTITUTION.

Rule 4.—Members of the Association shall be either Honorary Members, Fellows, Ordinary Members, or Student Members.

Rule 5.—*Ordinary Members* shall be more than twenty-three years of age, and shall be persons occupying responsible positions. They shall be :—
either (a) persons engaged in the manufacture, working, or use of non-ferrous metals and alloys ;
or (b) persons of scientific, technical, or literary attainments connected with or interested in the metal trades or with the application of non-ferrous metals and alloys.

Student Members shall be more than seventeen years of age, and shall not remain Student Members of the Association after they are twenty-five years of age, and shall be :—
either (a) Students of Metallurgy ;
or (b) pupils or assistants of persons qualified for ordinary membership whether such persons are actually members of the Association or not.

Student Members shall not be eligible for election on the Council nor entitled to vote at the Meetings of the Association.

SECTION II.—ELECTION OF MEMBERS.

Rule 6.—Applications for membership shall be in writing in the form marked "A," and such application must be signed by the applicant and not less than three members of the Association.

Rule 7.—Such applications for membership as Ordinary Members or Student Members as are approved by the Council shall be inserted in voting lists. These voting lists will constitute the ballot papers, and will specify the name, occupation, address, and proposers of each candidate. They shall be forwarded to the members for return to the Secretary at a fixed date, and four-fifths of the votes recorded shall be necessary for the election of any person.

Every such election shall be subject to the payment by the applicant of his entrance fee and first annual subscription, and he shall not become a member of the Association nor be entered on the Register of Members until such sums are actually received from him. In the event of his failing to pay such sums within the time specified in the notification to him of his election, his election shall be void.

Rule 8.—Upon election under the preceding Article the Secretary shall forward to the applicant so elected notice thereof in writing in the form marked "B."

Rule 9.—In the case of non-election, no mention thereof shall be made in the minutes.

SECTION VI.—SUBSCRIPTIONS.

Rule 28.—The subscription of each Ordinary Member shall be two guineas per annum, and of each Student Member one guinea per annum. Ordinary Members shall pay an entrance fee of two guineas each, and Students an entrance fee of one guinea each.

Rule 29.—Subscriptions shall be payable in advance on July 1st in each year, save in the case of Ordinary Members and Student Members elected under Clauses 6 and 7 hereof, whose entrance fee and annual subscription shall become payable in accordance with the notification to them of their election. Every subscription shall cover the period down to the 30th of June next following, and no longer.

Rule 30.—Subject to the provisions of Clause 7 hereof, any member whose subscription shall be six months in arrear, shall forfeit temporarily all the privileges of the Association. Due notice on the form following marked "C" shall be given to such member, and if such subscription remains unpaid upon the date specified for payment in this notice, the Council may remove such member from the Register of Members of the Association, and thereupon any member whose name is so removed shall cease to be a member thereof, but shall nevertheless remain liable to the Association for such arrears.

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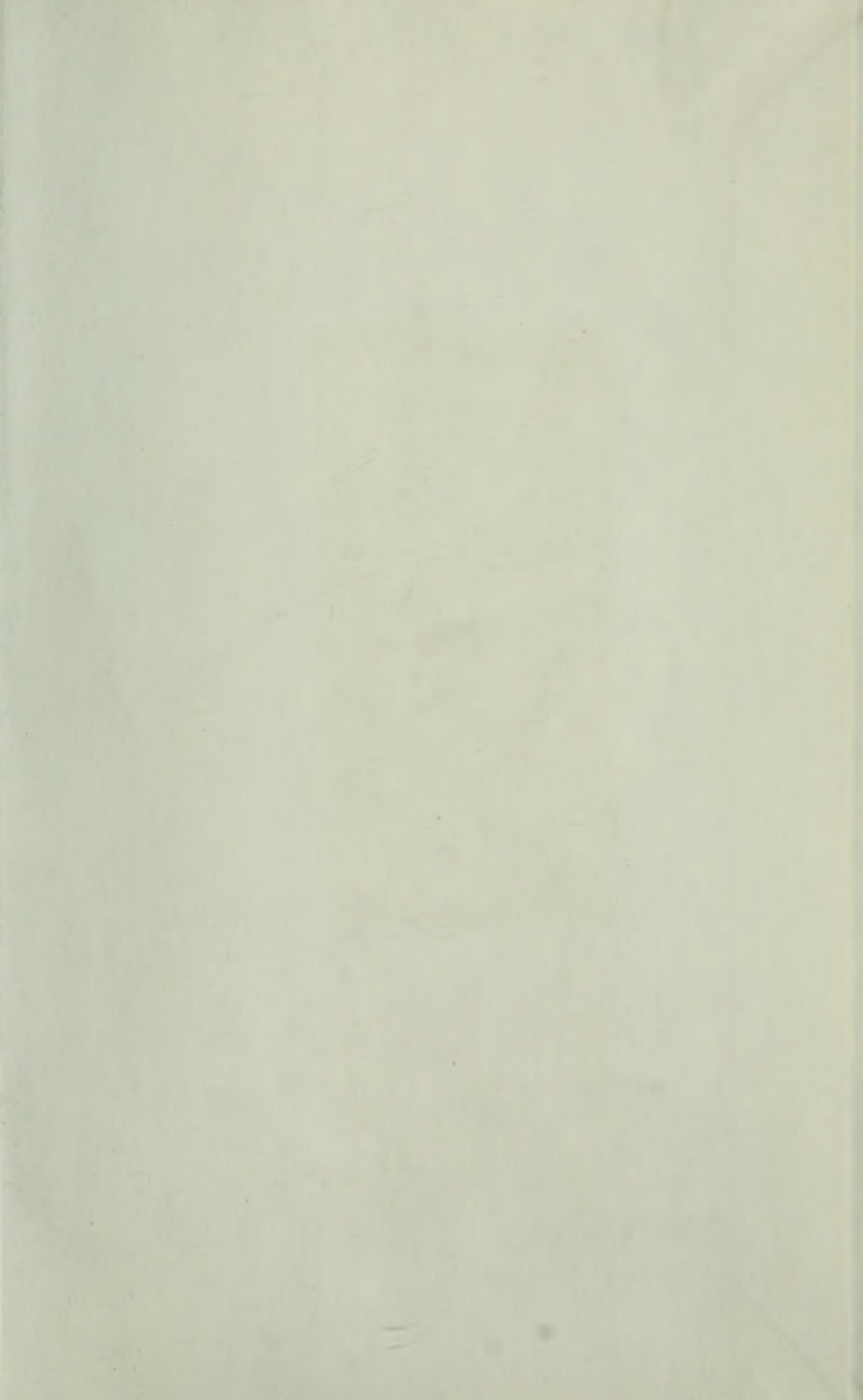
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